Nonlinear Feed Formulation For Broiler: Modeling And Optimization

Marcel Alessandro de Almeida[1]; Manoel Garcia Neto[2]; Max José de Araujo Faria Junior[2]; Marcos Franke Pinto[2]; Leda Gobbo de Freitas Bueno[2]

[1]Master by the Graduate Program in Animal Science - UNESP, Araçatuba.

[2] Professor of the Department of Support, Production and Animal Health - UNESP / Araçatuba, SP Brazil - Rua. Clovis Pestana, 793 - Bairro Dona Amélia - Araçatuba / SP

Zip code 16050-680 phone: 55 (18) 3636-1400

Corresponding author: leda.bueno@unesp.br

Summary

The current scenario requires the application of new computational tools for the feed formulation strategy that uses mathematical modeling in decision making. Noteworthy is the nonlinear programming, which aims not only to formulate a diet that meets the needs of the animal, but also the minimum cost and the maximum profit margin. Thus, the work aimed to validate the use of the nonlinear model (NLM), with maximization of the economic return, through estimates of animal performance and feed costs, according to the price variation of the kg of the broiler (price historical average of 2009 and 2010), the phases of creation and sex. For this purpose, 480 broiler broiler chickens, 240 males and 240 females of the same strain (Cobb 500) were used, from 1 to 56 days of age. The experimental design was entirely randomized, totaling 6 treatments (increasing or decreasing the average historical price of live chicken by 25% or 50%), with 4 replicates and 10 broiler chickens per experimental plot. Performance (weight gain and feed consumption), total energy consumption and profit margin were evaluated. Regarding the formulation principle (Linear and Nonlinear), the performance was very similar in relation to the studied parameters. However, when simulated values of 50% below the historical average, performance was significantly impaired in this specific condition. However, due to the profit margin, it demonstrated that the principle of nonlinear formulation allows to significantly reduce losses (P <0.05), mainly in unfavorable conditions of the price of chicken in the market. It is concluded that the nonlinear principle is more appropriate, since the requirements of all nutrients are automatically adjusted by the mathematical model and with the premise of increasing profitability, different from the linear one, which is to achieve maximum performance and not is directly related to the economic factor.

Keywords: data modeling, nonlinear programming, nutritional strategies, optimization, profitability.

1. INTRODUCTION

The industry's search for a constant increase in productivity and profit, which involves not only greater slaughter weight at a younger age, but also higher carcass and cut yields; in addition to the growing consumer demand for lean meat intake, it imposes a challenge on feed formulators. This is because dealing with cost-benefit relations presupposes the integration of biological and economic aspects [3].

The commercial formulation of diets for broilers consists of combining ingredients in appropriate proportions to achieve the appropriate and desired nutritional profile, aiming at the optimum level between performance and cost and, consequently, maximum profitability [10].

An alternative to help in making decisions and defining better and more economical products is the use of computational modeling. This methodology seeks to transform pertinent concepts and knowledge into mathematical equations and implements them through logical processes, simulating real situations on a computer [14].

Efficiency in feed formulation is one of the needs of the animal production industry. Animal performance and development are directly linked to food intake and in order to meet the animal's requirement at a certain stage of production, it is very important that the diet is formulated efficiently [17] [19].

To improve the commercial production process, precision models of feed consumption, growth and carcass yields are of crucial importance for the economy [20].

Thus, the linear model (LM), by defining only the minimum cost of the feed, will not necessarily allow a maximum profit, hence its great limitation. This limitation promoted the development of the nonlinear concept, which seeks the best gain rates, however, allying the minimum cost diets that meet nutritional requirements [8].

The present study aimed to validate the use of a nonlinear simulation spreadsheet, with maximization of the economic return, through estimates of poultry performance and production costs, according to the variation in the price of kg of broiler and the phases from creation.

2. MATERIAL AND METHODS

The experiments were carried out in the Animal Science Sector of the Faculty of Veterinary Medicine of Araçatuba (FMVA), at Universidade Estadual Paulista (UNESP). Two experiments I (females) and II (males) were carried out, consisting of diets formulated according to the linear (minimum cost) and nonlinear (maximum profit) systems. Commercial broiler chickens (Cobb 500) were used, with 240 males and 240 females, from 1 to 56 days. The experiment was approved by the Commitee for Ethical Use Animals (CEUA) of São Paulo State University (UNESP) at campus Faculty of Veterinary Medicine (FMVA) at campus Araçatuba / SP under protocol number 008872012.

The experimental design was completely randomized, totaling 6 treatments for each experiment, and four repetitions according to the price per kg of chicken paid (normal LM, + 50%, + 25%, -50%, -25% and normal NLM) .

Subsequently, to assess the economic viability, a completely randomized design was used, with 10 treatments and four replications.

To house the broiler chickens, a masonry shed (7.85 x 45.70 m) was used, with East-West orientation, air-conditioned by an adiabatic evaporative cooling system with negative pressure ventilation, covered with tiles made of insulating material (expanded polystyrene) disposed between reflective metal plates. Inside, the chickens were placed in boxes, with a tubular feeder and pendulum drinker for each, with dimensions of 1.4 x 3.0 m, which were constituted in the experimental plots, with a bed of wood shavings and an animal density 2.38 chickens/m².

One-day-old broiler chickens were weighed and randomly distributed in 48 boxes (four replicates with 10 chickens per treatment). As initial heating sources, porcelain cones with electrical resistance of 400W were used, with one remaining in each compartment during the first 15 days of creation.

The diets were formulated based on corn, soybean meal, soybean oil, vitamin supplement, mineral supplement, limestone and dicalcium phosphate, using the recommendations of [16], according to the linear (minimum cost ration) and nonlinear (maximum profit ration) according to the mathematical model of [5] that determined the feeding strategy for males and females of broilers, defined by the Practical Program for Feed Formulation (PPFR) (Tables 1 and 2).

The results were subjected to analysis of variance to verify the effects of treatments according to the PROC GLM system procedures [18]. In order to verify the significance of the differences between treatment means, the T test (LSD) was applied.

As there are differences between the growth rates for males and females, with different nutritional recommendations, and due to the different formulations imposed by nonlinear programming, the possibility of using a factorial scheme was disregarded [15].

According to [4], the responses for the production of broilers, corresponding to age and the energy content of the diet, understood as being "nutritional density", are defined through the quadratic function, as to the equations.

The complete models adjusted for broilers from 1 to 20 days[1]:

$$\textit{Female live weight} = -2629{,}392616 + 1{,}786173 * ME - 15{,}325394 * A - 0{,}000298 * ME^2 + 0{,}009547 * A * ME - 1{,}03314 * A^2$$

$$\textit{Male live weight} = -3354{,}330916 + 2{,}275183 * ME - 26{,}024964 * A - 0{,}00038 * ME^2 + 0{,}012768 * A * ME - 1{,}238741 * A^2$$

$$\textit{Female feed consumption} = -2141{,}109982 + 1{,}396249 * ME + 26{,}434941 * A - 0{,}000223 * ME^2 + 0{,}007556 * A * ME + 2{,}376905 * A^2$$

$$\textit{Male feed consumption} = -2733{,}306358 + 1{,}782576 * ME + 26{,}410652 * A - 0{,}000285 * ME^2 + 0{,}008886 * A * ME + 2{,}819171 * A^2$$

[1] ME and A represent the Metabolizable Energy and the Age, respectively.

The complete models adjusted for broilers from 21 to 56 days[1]:

$$\textit{Female live weight} = -31935 + 20{,}016453 * ME + 83{,}445201 * A - 0{,}03237 * ME^2 + 0{,}003767 * A * ME - 0{,}232548 * A^2$$

$$\textit{Male live weight} = -25781 + 15{,}988609 * ME + 64{,}70638 * A - 0{,}002608 * ME^2 + 0{,}015006 * A * ME - 0{,}213817 * A^2$$

$$\textit{Female feed consumption} = -49998 + 31{,}196913 * ME + 219{,}350257 * A - 0{,}004999 * ME^2 + 0{,}034783 * A * ME - 0{,}749763 * A^2$$

$$\textit{Male feed consumption} = -37547 + 24{,}056064 * ME + 257{,}506049 * A - 0{,}00381 * ME^2 + 0{,}042241 * A * ME - 0{,}792996 * A^2$$

[1] ME and A represent the Metabolizable Energy and the Age, respectively.

The objective functions for profit margin (PM) for males (PMm) and females (PMf) were obtained[1]:

PMm = -0.879527 + 0.090166 × A-0.019683 × PM-0.000576 × A ^ 2 + 0.001738 × PM × A

PMf = -0.613252 + 0.075129 × A-0.012823 × PM-0.000615 × A ^ 2 + 0.00135 × PM × A

[1] *A represent the Age.*

The broilers were evaluated through their body weight gain, feed intake and feed conversion index.

Weight gain (g / broiler / period), feed intake (g / broiler / period) and feed conversion were verified at 21°, 42° and 56° days of age.

From these data, the bioeconomic index (IBE), adapted from [6], Economic efficiency (EFE) adapted by [7] and Bioeconomic Energy Conversion (BEC), was calculated in order to reduce the distortions made by the indices.

As they do not consider energy in the evaluation of economic efficiency, IBE and EFE would not be appropriate, due to the fact that in the nonlinear model diets with different energy levels are formulated in the same creation phase, which does not occur in the linear model, which formulates diets with defined energy requirements, that is why in this work the BEC (Bioeconomic Energy Conversion) index was proposed in order to evaluate this new formulation principle.

The BEC Eq formula (1) integrates the total energy intake (TEI) in Megacalories (Mcal), the weighted cost of the feed (WCF) in (R$/kg), the weight gain (WG) in (kg) and the price of live chicken (PC)(R$/kg).

$$\boldsymbol{BEC} = \frac{TEI \times WCF}{WG \times PC}\ (Mcal/kg) \qquad \text{Eq (1)}$$

It is observed that the cost per kg of the feed should be the weighted (WCF) Eq (2), because this way an average value of the feed cost is obtained with greater accuracy. Therefore the weighted cost for the experiment was:

$$\boldsymbol{WCF} = \frac{\text{IFC}\times 21 + \text{GFC}\times 21 + \text{TFC}\times 14}{56} \qquad \text{Eq(2)}$$

Where: IFC = initial feed cost; GFC = growth feed cost; TFC = termination feed cost.

In relation to the other indexes, EFE [7], it was calculated in relation to the income obtained by weight gain and the cost invested in food in each period Eq (3), thus allowing an economic view of productivity in our market [7] through the currency of the Federal Republic of Brazil (R$) and the IBE [6] [12], used it to perform the calculation the average weight gain in the period, the relationship between the price of 1kg of feed (PF) and the sale price of 1kg of live chicken (PC) and the average feed consumption (FC), in each treatment Eq (4) .

$$\boldsymbol{EFE} = \frac{Weight\ gain\ income}{feed\ cost}\ (R\$/R\$) \qquad \text{Eq (3)}$$

$$\boldsymbol{IBE} = \text{weight gain} - \left|\left(\frac{PF}{PC}\right) \times \text{FC}\right|\ \text{(kg)} \qquad \text{Eq(4)}$$

Table 1 - Composition of the feed ingredients (%) and the calculated nutrient content of the diet (%), according to the stages and requirements for females.

Ingredients	Starter (1 a 21 days of age)						Grower (22 a 42 days of age)						Finisher (43 a 56 days of age)					
	Nonlinear spreadsheet					Linear spreadsheet	Nonlinear spreadsheet					Linear spreadsheet	Nonlinear spreadsheet					Linear spreadsheet
	Price per kilogram of Broiler						Price per kilogram of Broiler						Price per kilogram of Broiler					
	0.82	1.23	1.64	2.05	2.46		0.82	1.23	1.64	2.05	2.46		0.82	1.23	1.64	2.05	2.46	
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Feed cost	0.582	0.624	0.657	0.671	0.678	0.662	0.511	0.531	0.531	0.535	0.535	0.614	0.464	0.495	0.501	0.506	0.506	0.000
Inert	0.000	0.000	0.000	0.000	0.000	0.000	1.890	0.000	0.000	0.000	0.000	0.000	6.227	0.000	0.000	0.000	0.000	66.737
Corn	61.881	62.135	58.692	57.258	56.507	56.893	67.259	72.664	72.664	73.556	73.534	65.413	66.041	70.427	72.777	74.816	74.816	4.733
Soy oil	0.000	1.398	3.096	3.803	4.173	3.566	0.000	0.000	0.000	0.000	0.012	4.225	0.000	0.000	0.000	0.000	0.000	25.076
Soybean mean -45%	34.293	32.277	33.930	34.618	34.978	35.313	27.909	24.047	24.047	23.074	23.085	26.814	25.036	26.699	24.184	22.003	22.003	1.359
Dicalcium phosphate	1.581	1.670	1.722	1.744	1.755	1.724	1.240	1.318	1.318	1.330	1.330	1.440	1.101	1.174	1.204	1.230	1.230	0.415
Common salt	0.447	0.458	0.471	0.476	0.479	0.472	0.382	0.397	0.397	0.398	0.398	0.427	0.351	0.375	0.378	0.382	0.382	0.000
L-Lysine HCl	0.109	0.225	0.214	0.209	0.206	0.176	0.000	0.158	0.158	0.193	0.192	0.158	0.000	0.000	0.090	0.167	0.167	0.165
DL-Methionine	0.189	0.237	0.249	0.254	0.257	0.242	0.084	0.132	0.132	0.142	0.142	0.166	0.065	0.069	0.095	0.118	0.118	0.153
L Threonine	0.000	0.055	0.056	0.056	0.056	0.041	0.000	0.000	0.000	0.015	0.015	0.013	0.000	0.000	0.000	0.000	0.000	0.012
Calcitic limestone	0.824	0.847	0.858	0.862	0.864	0.856	0.721	0.753	0.753	0.756	0.756	0.777	0.662	0.706	0.716	0.725	0.725	0.749
Polimax F-pre initial (Fatec)	0.676	0.698	0.714	0.721	0.725	0.716	0.515	0.533	0.533	0.535	0.535	0.567	0.000	0.000	0.000	0.000	0.000	0.000
Polimax F-3 finishing (Fatec)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.517	0.551	0.556	0.561	0.561	0.600
Calculated composition																		
Metabolizable Energy (Kcal kg-1)	2.877	2.970	3.040	3.070	3.085	3.050	2.907	3.010	3.010	3.020	3.021	3.200	2.800	2.986	3.013	3.036	3.036	3.250
Crude protein (%)	20.865	20.152	20.613	20.805	20.906	21.041	18.252	17.125	17.125	16.808	16.811	17.810	16.839	17.957	17.111	16.377	16.377	17.130
Calcium (%)	0.805	0.831	0.850	0.858	0.863	0.853	0.668	0.691	0.691	0.694	0.694	0.735	0.604	0.644	0.650	0.655	0.655	0.701
Available phosphorus (%)	0.404	0.417	0.427	0.431	0.433	0.428	0.333	0.345	0.345	0.346	0.346	0.367	0.302	0.322	0.324	0.327	0.327	0.350
Potassium (%)	0.801	0.765	0.785	0.794	0.798	0.806	0.699	0.644	0.644	0.628	0.628	0.674	0.643	0.686	0.646	0.612	0.612	0.646
Sodium(%)	0.197	0.201	0.205	0.207	0.208	0.206	0.171	0.177	0.177	0.177	0.177	0.188	0.158	0.168	0.170	0.171	0.171	0.183
Chlorine (%)	0.336	0.364	0.368	0.370	0.371	0.362	0.275	0.315	0.315	0.323	0.323	0.331	0.255	0.272	0.291	0.308	0.308	0.325
Linoleic acid	1.362	2.107	2.971	3.331	3.519	3.201	1.418	1.491	1.491	1.501	1.507	3.655	1.376	1.468	1.494	1.517	1.517	3.942
Dig. Lysine	1.086	1.121	1.147	1.158	1.164	1.151	0.853	0.883	0.883	0.886	0.886	0.939	0.777	0.829	0.836	0.843	0.843	0.902
Dig. Methionine	0.484	0.519	0.535	0.541	0.545	0.533	0.352	0.385	0.385	0.391	0.391	0.423	0.314	0.335	0.350	0.362	0.362	0.403
Dig. Methionine + Cystine	0.771	0.796	0.814	0.822	0.826	0.817	0.614	0.636	0.636	0.638	0.638	0.676	0.559	0.596	0.602	0.606	0.606	0.649
Dig. Tryptophan	0.229	0.218	0.225	0.228	0.230	0.232	0.197	0.178	0.178	0.173	0.173	0.189	0.180	0.192	0.179	0.168	0.168	0.180
Dig. Threonine	0.705	0.728	0.746	0.753	0.757	0.748	0.620	0.574	0.574	0.576	0.576	0.610	0.571	0.609	0.576	0.547	0.547	0.586
Dig. Arginine	1.320	1.257	1.297	1.314	1.323	1.335	1.135	1.031	1.031	1.003	1.003	1.094	1.039	1.108	1.036	0.973	0.973	1.043
Dig. Valine	0.878	0.840	0.860	0.869	0.873	0.881	0.774	0.718	0.718	0.703	0.703	0.746	0.714	0.762	0.721	0.687	0.687	0.718
Dig. Isoleucine	0.819	0.781	0.804	0.814	0.819	0.826	0.711	0.651	0.651	0.634	0.634	0.685	0.652	0.696	0.654	0.617	0.617	0.655
Dig. Leucine	1.704	1.642	1.662	1.670	1.674	1.689	1.551	1.479	1.479	1.456	1.457	1.498	1.447	1.543	1.485	1.434	1.434	1.455
Dig. Histidine	0.529	0.507	0.517	0.522	0.524	0.529	0.471	0.441	0.441	0.433	0.433	0.455	0.436	0.465	0.443	0.424	0.424	0.439
Dig. Phenylalanine	0.959	0.917	0.940	0.949	0.954	0.963	0.843	0.781	0.781	0.764	0.764	0.813	0.778	0.829	0.784	0.745	0.745	0.781
Dig. Phenylalanine+Tyrosine	1.618	1.547	1.584	1.600	1.608	1.623	1.423	1.319	1.319	1.289	1.290	1.372	1.312	1.399	1.324	1.259	1.259	1.318
Energy:Protein Ratio	137.869	147.391	147.495	147.538	147.559	144.958	159.250	175.753	175.753	179.674	179.674	179.674	166.285	166.285	176.079	185.394	185.394	189.726

Vitamin-mineral supplements used in diets in three rearing stages (quantity / kg of product) included: pre Initial: vit. A - 1,835,000 I.U. vit. D3 - 335,000 I.U. vit. E - 2,835 mg; vit. K3 - 417 mg; vit. B1 - 335 mg; vit. B2 - 1,000 mg; vit. B6 - 335 mg; vit. B12 - 2,500 mcg; folic acid - 135 mg; biotin - 17 mg; niacin - 6,670 mg; calcium pantothenate - 1,870 mg; Cu - 1,000 mg; Co - 35 mg; I - 170 mg; Fe - 8,335 mg; Mn - 10,835mg; Zn - 8,335 mg; Se - 35 mg; Choline Chloride 50% - 135,000 mg; Methionine - 267,000 mg; Coccidiostatic - 13,335 mg; Growth Promoter - 16,670 mg; Antioxidant - 2,000 mg. Termination: vit. A - 1,670,000 I.U. vit. D3 - 335,000 I.U. vit. E - 2,335 mg; vit. K3 - 400 mg; vit. B1 - 100 mg;

vit. B2 - 800 mg; vit. B6 - 200 mg; vit. B12 - 2,000 mcg; folic acid - 67 mg; biotin - 7 mg; niacin - 5,670 mg; calcium pantothenate - 2,000 mg; Cu - 2,000 mg; Co - 27 mg; I - 270 mg; Fe - 16,670 mg; Mn - 17,335 mg; Zn - 12,000 mg; Se - 70 mg; Choline Chloride 50% - 100,000mg; Methionine - 235,000mg; Antioxidant - 2,000 mg.

Table 2 - Composition of feed ingredients (%) and calculated nutrient content of the diet (%), according to the stages and requirements for males.

Ingredients	Starter (1 a 21 days of age)						Growero (22 a 42 days of age)						Finisher (43 a 56 days of age)					
	Nonlinear spreadsheet					Linear spreadsheet	Nonlinear spreadsheet					Linear spreadsheet	Nonlinear spreadsheet					Linear spreadsheet
	Price per kilogram of Broiler						Price per kilogram of Broiler						Price per kilogram of Broiler					
	0.82	1.23	1.64	2.05	2.46		0.82	1.23	1.64	2.05	2.46		0.82	1.23	1.64	2.05	2.46	
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Feed cost	0.599	0.659	0.686	0.696	0.702	0.677	0.511	0.542	0.544	0.556	0.586	0.648	0.507	0.517	0.517	0.525	0.534	0.631
Inert	0.000	0.000	0.000	0.000	0.000	0.000	0.312	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Corn	63.092	57.260	54.458	53.392	52.852	54.196	62.110	68.270	68.867	69.663	66.603	60.152	66.476	70.242	70.242	72.193	71.275	61.183
Soy oil	0.000	3.004	4.371	4.891	5.155	4.091	0.000	0.000	0.000	0.293	1.859	5.161	0.000	0.000	0.000	0.000	0.476	5.717
Soybean mean -45%	32.679	35.304	36.662	37.179	37.441	37.301	30.846	28.368	27.716	26.489	27.910	30.905	30.535	26.512	26.512	24.387	24.806	29.423
Dicalcium phosphate	1.707	1.808	1.852	1.868	1.877	1.830	1.257	1.358	1.366	1.393	1.436	1.526	1.215	1.264	1.264	1.291	1.303	1.438
Common salt	0.472	0.496	0.507	0.511	0.513	0.503	0.398	0.412	0.414	0.418	0.429	0.453	0.400	0.395	0.395	0.399	0.402	0.438
L-Lysine HCl	0.215	0.208	0.199	0.195	0.194	0.167	0.000	0.137	0.161	0.213	0.202	0.180	0.000	0.145	0.145	0.222	0.219	0.183
DL-Methionine	0.233	0.259	0.269	0.272	0.274	0.256	0.116	0.161	0.168	0.186	0.196	0.218	0.105	0.148	0.148	0.171	0.174	0.207
L Threonine	0.049	0.056	0.057	0.057	0.057	0.042	0.000	0.000	0.010	0.034	0.034	0.034	0.000	0.000	0.000	0.033	0.033	0.034
Calcitic limestone	0.874	0.895	0.904	0.908	0.909	0.898	0.723	0.769	0.772	0.779	0.788	0.805	0.725	0.742	0.742	0.750	0.753	0.778
Polimax F-pre initial (Fatec)	0.678	0.708	0.721	0.726	0.729	0.716	0.496	0.524	0.526	0.531	0.542	0.567	0.000	0.000	0.000	0.000	0.000	0.000
Polimax F-3 finishing (Fatec)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.543	0.551	0.551	0.555	0.559	0.600
Calculated composition																		
Metabolizable Energy (Kcal kg-1)	2.888	3.015	3.071	3.092	3.103	3.050	2.800	2.959	2.966	2.994	3.060	3.200	2.940	2.984	2.984	3.006	3.027	3.250
Crude protein (%)	20.397	21.119	21.500	21.645	21.719	21.719	19.176	18.718	18.506	18.094	18.481	19.296	19.390	18.040	18.040	17.349	17.462	18.706
Calcium (%)	0.851	0.889	0.905	0.912	0.915	0.899	0.678	0.717	0.718	0.725	0.741	0.775	0.669	0.679	0.679	0.684	0.689	0.740
Available phosphorus (%)	0.425	0.444	0.452	0.455	0.457	0.449	0.338	0.357	0.358	0.361	0.369	0.386	0.333	0.338	0.338	0.340	0.343	0.368
Potassium (%)	0.775	0.806	0.823	0.830	0.833	0.834	0.738	0.710	0.700	0.680	0.697	0.734	0.745	0.682	0.682	0.648	0.654	0.710
Sodium(%)	0.206	0.216	0.220	0.221	0.222	0.218	0.177	0.183	0.184	0.185	0.189	0.198	0.178	0.176	0.176	0.178	0.179	0.192
Chlorine (%)	0.371	0.382	0.386	0.388	0.389	0.378	0.284	0.321	0.326	0.339	0.342	0.350	0.287	0.312	0.312	0.329	0.330	0.342
Linoleic acid	1.374	2.905	3.599	3.864	3.998	3.448	1.343	1.439	1.446	1.610	2.408	4.091	1.421	1.463	1.463	1.485	1.727	4.400
Dig. Lysine	1.126	1.175	1.197	1.206	1.210	1.189	0.917	0.969	0.971	0.981	1.002	1.048	0.918	0.932	0.932	0.939	0.945	1.015
Dig. Methionine	0.519	0.550	0.563	0.568	0.570	0.554	0.392	0.432	0.436	0.448	0.461	0.489	0.386	0.411	0.411	0.424	0.428	0.471
Dig. Methionine + Cystine	0.799	0.834	0.850	0.856	0.859	0.844	0.661	0.698	0.700	0.706	0.722	0.755	0.661	0.671	0.671	0.676	0.681	0.731
Dig. Tryptophan	0.221	0.232	0.238	0.240	0.241	0.241	0.210	0.200	0.197	0.190	0.196	0.209	0.211	0.191	0.191	0.180	0.182	0.201
Dig. Threonine	0.732	0.764	0.778	0.784	0.787	0.773	0.652	0.630	0.631	0.637	0.651	0.681	0.659	0.606	0.606	0.610	0.615	0.660
Dig. Arginine	1.273	1.336	1.369	1.382	1.388	1.389	1.211	1.154	1.135	1.098	1.133	1.206	1.216	1.101	1.101	1.040	1.050	1.162
Dig. Valine	0.852	0.882	0.898	0.904	0.908	0.910	0.813	0.786	0.776	0.755	0.772	0.807	0.822	0.758	0.758	0.723	0.728	0.782
Dig. Isoleucine	0.791	0.827	0.846	0.853	0.856	0.857	0.754	0.722	0.711	0.690	0.709	0.750	0.759	0.692	0.692	0.656	0.662	0.724
Dig. Leucine	1.664	1.692	1.709	1.715	1.718	1.727	1.596	1.576	1.560	1.529	1.545	1.579	1.628	1.535	1.535	1.486	1.490	1.541
Dig. Histidine	0.514	0.529	0.538	0.541	0.542	0.544	0.491	0.479	0.473	0.461	0.470	0.487	0.498	0.463	0.463	0.444	0.446	0.473
Dig. Phenylalanine	0.930	0.964	0.982	0.989	0.993	0.995	0.887	0.857	0.845	0.822	0.841	0.881	0.896	0.825	0.825	0.787	0.792	0.853
Dig. Phenylalanine+Tyrosine	1.567	1.625	1.656	1.667	1.673	1.677	1.496	1.446	1.426	1.387	1.419	1.485	1.512	1.392	1.392	1.328	1.337	1.439
Energy:Protein Ratio	141.590	142.767	142.843	142.872	142.886	140.432	146.015	158.082	160.261	165.472	165.594	165.837	151.636	165.389	165.389	173.276	173.318	173.742

Vitamin-mineral supplements used in diets in three rearing stages (quantity / kg of product) included: pre Initial: vit. A - 1,835,000 I.U. vit. D3 - 335,000 I.U. vit. E - 2,835 mg; vit. K3 - 417 mg; vit. B1 - 335 mg; vit. B2 - 1,000 mg; vit. B6 - 335 mg; vit. B12 - 2,500 mcg; folic acid - 135 mg; biotin - 17 mg; niacin - 6,670 mg; calcium pantothenate - 1,870 mg; Cu - 1,000 mg; Co - 35 mg; I - 170 mg; Fe - 8,335 mg; Mn - 10,835mg; Zn - 8,335 mg; Se - 35 mg; Choline Chloride 50% - 135,000 mg; Methionine - 267,000 mg; Coccidiostatic - 13,335 mg; Growth Promoter - 16,670 mg; Antioxidant - 2,000 mg. Termination: vit. A - 1,670,000 I.U. vit. D3 - 335,000 I.U. vit. E - 2,335 mg; vit. K3 - 400 mg; vit. B1 - 100 mg; vit. B2 - 800 mg; vit. B6 - 200 mg; vit. B12 - 2,000 mcg; folic acid - 67 mg; biotin - 7 mg; niacin - 5,670 mg; calcium pantothenate - 2,000 mg; Cu - 2,000 mg; Co - 27 mg; I - 270 mg; Fe - 16,670 mg; Mn - 17,335 mg; Zn - 12,000 mg; Se - 70 mg; Choline Chloride 50% - 100,000mg; Methionine - 235,000mg; Antioxidant - 2,000 mg.

3. RESULTS AND DISCUSSION

Regarding the formulation principle (Linear and Nonlinear), the performance (Tables 3 and 4) was very similar in relation to the studied parameters. However, when simulated values of 50% below the historical average, performance was significantly impaired in this specific condition.

If all essential nutrients are maintained in an adequate proportion to the energy density of the diet, body weight and feed conversion are favored by increasing the energy density of the feed.

This condition makes it possible to apply models for maximum profit (nonlinear formulation), aiming to estimate the most appropriate proportion of weight gain according to the price paid by the market, producing quality carcasses.

This worsening in live weight, weight gain, feed consumption and feed conversion is mainly due to the lower energy : nutrient content offered in this diet (-50%), which was inherent to the formulation principle (nonlinear), which does not aim at the best broiler performance, but at the economic optimization of production.

As for the profit margin (Table 5), it was demonstrated that the principle of nonlinear formulation allows to significantly reduce losses (P <0.05), mainly under unfavorable conditions in the market price of chicken.

Table 3 - Live weight, weight gain, feed intake and feed conversion for female broilers, according to age and the linear model (LM) and nonlinear model (NLM) formulation principle.

	Live weight (kg)			Weight gain (kg)			Feed consuption (kg)			Food conversion (kg/kg)		
Trataments	1 - 21 days	1 - 42 days	1 - 56 days	1 - 21 days	1 - 42 days	1 - 56 days	1 - 21 days	1 - 42 days	1 - 56 days	1 - 21 days	1 - 42 days	1 - 56 days
Normal LM	0.93 **a**	2.71 **a**	3.81 **a**	0.89 **a**	2.7 **a**	3.8 **a**	1.3 **a**	4.8 **b**	7.4 **b**	1.4 **b**	1.8 **c**	2.0 **c**
NLM+25%	0.94 **a**	2.63 **ab**	3.67 **ab**	0.89 **a**	2.6 **ab**	3.6 **ab**	1.3 **a**	4.9 **ab**	7.9 **ab**	1.4 **b**	1.9 **ab**	2.2 **ab**
NLM+50%	0.93 **a**	2.63 **ab**	3.64 **ab**	0.88 **a**	2.6 **ab**	3.6 **ab**	1.3 **a**	4.9 **ab**	7.6 **ab**	1.4 **b**	1.9 **b**	2.1 **b**
NLM-25%	0.88 **bc**	2.59 **ab**	3.60 **b**	0.84 **bc**	2.5 **ab**	3.6 **b**	1.3 **a**	4.9 **ab**	7.7 **ab**	1.5 **b**	1.9 **b**	2.2 **b**
NLM-50%	0.85 **c**	2.56 **b**	3.60 **b**	0.80 **c**	2.5 **b**	3.6 **b**	1.3 **a**	5.0 **a**	8.0 **a**	1.6 **a**	2.0 **a**	2.3 **a**
Normal NLM	0.91 **ab**	2.61 **ab**	3.63 **ab**	0.87 **ab**	2.6 **ab**	3.6 **ab**	1.3 **a**	4.9 **ab**	7.8 **ab**	1.5 **b**	1.9 **ab**	2.2 **ab**
P	0.0004	0.2437	0.2524	0.0004	0.2437	0.2524	0.3038	0.3534	0.2938	0.0027	0.0024	0.0010
CV (%)	2.82	3.16	3.54	0.69	3.22	3.58	3.44	3.25	5.09	4.87	2.95	3.42

[a-b] Mean values with same letter within a column are not significantly different (P<0.05); * kg of paid chicken (normal, + 25%, + 50%, -25% and -50%), according to the historical price from 2009 to 2010.

Table 4 - Live weight, weight gain, feed intake and feed conversion for male broilers, according to age and the linear model (LM) and nonlinear model (NLM) formulation principle.

	Live weight (kg)			Weight gain (kg)			Feed consuption (kg)			Food conversion (kg/kg)		
Trataments	1 - 21 days	1 - 42 days	1 - 56 days	1 - 21 days	1 - 42 days	1 - 56 days	1 - 21 days	1 - 42 days	1 - 56 days	1 - 21 days	1 - 42 days	1 - 56 days
Normal LM	1.03 **ab**	3.25 **a**	4.74 **a**	0.98 **ab**	3.20 **a**	4.69 **a**	1.4 **ab**	5.2 **c**	8.4 **c**	1.4 **b**	1.6 **c**	1.8 **c**
NLM+25%	1.05 **a**	3.06 **b**	4.38 **b**	1.00 **a**	3.01 **b**	4.34 **b**	1.3 **ab**	5.3 **bc**	8.4 **c**	1.3 **b**	1.8 **b**	1.9 **b**
NLM+50%	1.04 **a**	3.22 **a**	4.53 **ab**	0.99 **a**	3.18 **a**	4.48 **ab**	1.3 **b**	5.4 **bc**	8.7 **bc**	1.3 **b**	1.7 **c**	1.9 **b**
NLM-25%	0.99 **b**	3.12 **ab**	4.55 **ab**	0.95 **b**	3.08 **ab**	4.50 **ab**	1.4 **a**	5.6 **ab**	8.9 **bc**	1.5 **a**	1.8 **b**	2.0 **b**
NLM-50%	0.95 **c**	3.13 **ab**	4.60 **ab**	0.90 **c**	3.09 **ab**	4.56 **ab**	1.4 **a**	5.8 **a**	9.5 **a**	1.6 **a**	1.9 **a**	2.1 **a**
Normal NLM	1.01 **ab**	3.13 **ab**	4.61 **ab**	0.97 **ab**	3.09 **ab**	4.56 **ab**	1.4 **ab**	5.5 **b**	9.0 **b**	1.4 **b**	1.8 **b**	2.0 **b**
P	0.0004	0.0800	0.1503	0.0004	0.0800	0.1506	0.1703	0.0022	0.0020	0.0002	<.0001	0.0002
CV (%)	0.69	2.83	3.78	0.69	2.88	3.81	0.33	3.19	3.91	4.86	2.41	3.40

[a-c] Mean values with same letter within a column are not significantly different (P<0.05); * kg of paid chicken (normal, + 25%, + 50%, -25% and -50%), according to the historical price from 2009 to 2010

Table 5 - Absolute profit margin for female and male broilers, according to the relative price of the chicken and the principle of linear and nonlinear formulation.

	Profit margin (R$) Female						Profit margin (R$) Male					
Relative price	Nonlinear 1-21 days	Linear 1-21 days	Nonlinear 1-42 days	Linear 1-42 days	Nonlinear 1-56 days	Linear 1-56 days	Nonlinear 1-21 days	Linear 1-21 days	Nonlinear 1-42 days	Linear 1-42 days	Nonlinear 1-56 days	Linear 1-56 days
N +50%	1.42 **a**	1.46 **a**	3.68 **a**	3.68 **a**	4.80 **a**	4.79 **a**	1.63 **a**	1.60 **a**	4.63 **a**	4.55 **a**	6.06 **a**	6.25 **a**
N +25%	1.07 **b**	1.08 **b**	2.57 **b**	2.57 **b**	3.20 **b**	3.23 **b**	1.21 **b**	1.18 **b**	3.11 **b**	3.22 **b**	4.20 **b**	4.31 **b**
Normal (N)¹	0.64 **c**	0.69 **c**	1.50 **c**	1.46 **c**	1.75 **c**	1.67 **c**	0.74 **c**	0.76 **c**	1.94 **c**	1.89 **c**	2.58 **c**	2.36 **c**
N -25%	0.30 **d**	0.31 **d**	0.49 **d**	0.35 **d**	0.35 **d**	0.11 **d***	0.28 **d**	0.34 **d**	0.65 **d**	0.56 **d**	0.70 **d**	0.42 **d**
N -50%	-0.07 **e**	-0.07 **e**	-0.56 **e**	-0.76 **e***	-1.11 **e**	-1.46 **e***	-0.08 **e**	-0.08 **e**	-0.53 **e**	-0.77 **e***	-1.20 **e**	-1.52 **e**
P	<.0001		<.0001		<.0001		<.0001		<.0001		<.0001	
CV (%)	7.82		8.96		8.78		6.24		6.22		10.49	

Statistically different means (*) on the line by the T test (P<0.05); 1 Historical average price from 2009 to 2010 (kg of broiler paid to the producer); a-e Mean values with same letter within a column are not significantly different (P<0.05).

Evaluating the EFE, IBE and BEC indices in the analysis of the bioeconomic profit margin (Tables 6 to 8). The data suggest that the bioeconomic energy conversion (BEC), proved to be more adequate to differentiate the evaluated formulation principles (Linear and Nonlinear), regardless of sex and period (Table 6). In relation to the bioeconomic indices evaluated (EFE, IBE and BEC / Tables 8 to 10), BEC differs by incorporating the most expensive item in a diet (energy), by measuring energy consumption according to bioeconomic conversion, that is, the best performance was analyzed in relation to the energy level of the diet. It follows that the lower the index, the better the cost/benefit ratio.

Table 6 - Absolute Bioeconomic Energy Conversion (BEC) for female and male broilers, according to the relative price of the chicken and the principle of linear and nonlinear formulation.

	Bioeconomic Energy Conversion (Female)						Bioeconomic Energy Conversion (Male)					
Relative price	Nonlinear 1-21 days	Linear 1-21 days	Nonlinear 1-42 days	Linear 1-42 days	Nonlinear 1-56 days	Linear 1-56 days	Nonlinear 1-21 days	Linear 1-21 days	Nonlinear 1-42 days	Linear 1-42 days	Nonlinear 1-56 days	Linear 1-56 days
N +50%	1.22 **e**	1.17 **e**	1.41 **e**	1.47 **e**	1.51 **e**	1.61 **e**	1.17 **e**	1.17 **e**	1.36 **e**	1.39 **e**	1.49 **e**	1.52 **e**
N +25%	1.43 **d**	1.40 **d**	1.71 **d**	1.76 **d**	1.87 **d**	1.93 **d**	1.41 **d**	1.40 **d**	1.63 **d**	1.67 **d**	1.72 **d**	1.82 **d**
Normal (N)¹	1.84 **c**	1.76 **c**	2.1 **c**	2.20 **c***	2.27 **c**	2.41 **c***	1.79 **c**	1.75 **c**	2.01 **c**	2.09 **c**	2.12 **c**	2.27 **c***
N -25%	2.26 **b**	2.34 **b**	2.69 **b**	2.93 **b***	2.92 **b**	3.22 **b***	2.43 **b**	2.34 **b**	2.63 **b**	2.79 **b***	2.77 **b**	3.03 **b***
N -50%	3.37 **a**	3.51 **a***	3.86 **a**	4.40 **a***	4.15 **a**	4.83 **a***	3.36 **a**	3.51 **a***	3.60 **a**	4.18 **a***	3.97 **a**	4.55 **a***
P	<.0001		<.0001		<.0001		<.0001		<.0001		<.0001	
CV (%)	4.46		2.33		3.05		4.49		2.49		3.55	

Statistically different means (*) on the line by the T test (P<0.05); [1] Relative price of the kg of the broiler paid to the producer. BEC =(total energy consumption×weighted feed cost/kg):(weight gain kg×live chicken cost); a-e Mean values with same letter within a column are not significantly different (P<0.05).

Through this strategy, and with the evolution from linear to nonlinear formulation, economic optimization by energy density becomes dependent, mainly, on the energy and protein prices of feed ingredients and the value of chicken/kg. This procedure, since it complies with the law of decreasing returns [2], admits through nonlinear programming the most adequate condition for energy density, which is not possible due to linear formulation [1] [13].

Therefore, to improve the energy density of a feed, it is necessary to use the nonlinear formulation.

Among the indexes evaluated (BEC, IBE and EFE), IBE presented the highest variation coefficient, with values between 9.48 to 20.27, demonstrating a great instability (Table 7). For EFE, the values were intermediate for CV, with values ranging from 2.96 to 4.67% (Table 8). As for BEC, the CV varied from 2.33 to 4.49%, thus demonstrating greater reliability for the evaluation of the averages of the current formulation principles (Table 6).

Table 7 - Absolute Bioeconomic Index (IBE) for female and male broilers, according to the relative price of the chicken and the principle of linear and nonlinear formulation.

	Bioeconomic Index (Female)						**Bioeconomic Index (Male)**					
	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear
Relative price	1-21 days	1-21 days	1-42 days	1-42 days	1-56 days	1-56 days	1-21 days	1-21 days	1-42 days	1-42 days	1-56 days	1-56 days
N +50%	0.53 **a**	0.55 **a**	1.38 **a**	1.43 **a**	1.81 **a**	1.87 **a**	0.62 **a**	0.61 **a**	1.77 **a**	1.79 **a**	2.30 **a**	2.47 **a**
N +25%	0.48 **b**	0.48 **b**	1.13 **b**	1.18 **b**	1.39 **b**	1.49 **b**	0.54 **b**	0.53 **b**	1.38 **b**	1.51 **b***	1.87 **b**	2.02 **b**
Normal (N)[1]	0.34 **c**	0.38 **c**	0.78 **c**	0.81 **c**	0.88 **c**	0.92 **c**	0.40 **c**	0.42 **c**	1.01 **c**	1.09 **c**	1.33 **c**	1.35 **c***
N -25%	0.20 **d**	0.21 **d**	0.26 **d**	0.19 **d**	0.09 **d**	-0.03 **d**	0.18 **d**	0.23 **d***	0.36 **d**	0.38 **d**	0.32 **d**	0.24 **d***
N -50%	-0.14 **e**	-0.13 **e**	-0.83 **e**	-1.04 **e***	-1.70 **e**	-1.93 **e***	-0.15 **e**	-0.15 **e**	-0.85 **e**	-1.03 **e***	-1.74 **e**	-1.99 **e***
P	<.0001		<.0001		<.0001		<.0001		<.0001		<.0001	
CV (%)	10.76		12.61		20.27		9.78		9.48		18.92	

Statistically different means (*) on the line by the T test (P<0.05); [1] Relative price of the kg of the broiler paid to the producer. IBE=weight gain – (A×CR), a being the ratio between the price of one kg of feed and the selling price of one kg of whole chicken (Guidoni, 1994; Meinerz et al., 2001); a-e Mean values with same letter within a column are not significantly different (P<0.05).

Table 8 - Absolute Bioeconomic Efficiency (EFE) for female and male broilers, according to the relative price of the chicken and the principle of linear and nonlinear formulation.

	Bioeconomic Efficiency (Female)						**Bioeconomic Efficiency (Male)**					
	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear	Nonlinear	Linear
Relative price	1-21 days	1-21 days	1-42 days	1-42 days	1-56 days	1-56 days	1-21 days	1-21 days	1-42 days	1-42 days	1-56 days	1-56 days
N +50%	2.53 **a**	2.61 **a**	2.28 **a**	2.20 **a***	2.13 **a**	2.02 **a***	2.65 **a**	2.61 **a**	2.37 **a**	2.29 **a***	2.17 **a**	2.14 **a**
N +25%	2.16 **b**	2.17 **b**	1.88 **b**	1.83 **b**	1.72 **b**	1.69 **b**	2.19 **b**	2.18 **b**	1.96 **b**	1.91 **b**	1.86 **b**	1.78 **b***
Normal (N)[1]	1.66 **c**	1.74 **c**	1.52 **c**	1.46 **c**	1.40 **c**	1.35 **c**	1.72 **c**	1.74 **c**	1.58 **c**	1.53 **c**	1.50 **c**	1.42 **c***
N -25%	1.31 **d**	1.30 **d**	1.16 **d**	1.10 **d**	1.07 **d**	1.01 **d***	1.25 **d**	1.31 **d**	1.19 **d**	1.15 **d**	1.13 **d**	1.07 **d**
N -50%	0.86 **e**	0.87 **e**	0.78 **e**	0.73 **e**	0.72 **e**	0.67 **e**	0.86 **e**	0.87 **e**	0.82 **e**	0.76 **e**	0.75 **e**	0.71 **e**
P	<.0001		<.0001		<.0001		<.0001		<.0001		<.0001	
CV (%)	4.67		3.00		2.96		3.87		2.53		3.66	

Statistically different means (*) on the line by the T test (P<0.05); [1] Relative price of the kg of the broiler paid to the producer. EFE = (weight gain income : feed cost)); a-e Mean values with same letter within a column are not significantly different (P<0.05).

According to the present experiment, it is evident that all the indexes evaluated (BEC, IBE and EFE) made it possible to measure the variations imposed on the normal market price (with ranges of 25 to 50%, for or less). In other words, what was already expected, due to the high magnitude imposed for price variation (increases or decreases of 25%).

However, in relation to the main objective of the present proposal, regarding the comparison between formulation principles (linear and nonlinear), the differences were extremely distinct, evidencing very well that there was much more quality and sensitivity of measurement by the BEC index.

Then, all indexes presented a significant (P) probability (P <0.0001). Despite this extremely favorable P, the different behavior between the different indices must be highlighted. While the EFE presented its values differentiated between the principles of formulation tending towards the higher relative prices, the IBE presented a trend towards the lower values of the relative price of the broiler. However, both rates were fluctuating.

The BEC, on the other hand, showed a more consistent behavior, with the statistical significance of the differences between the averages associated with the lower ranges of relative price of the broiler, showing less oscillation of the trend and greater coherence of the index.

It was observed that for both females and males, the amount of abdominal fat is related to the formulation principle, being significantly favorable (P <0.05) for nonlinear. Because there is a worse use of energy (deviated to fat deposition) for the principle of linear formulation (Tables 9 to 12).

The average values for the absolute weight and the weight of the body components of the broilers, in grams, are presented in Tables 9 to 12. However, the body composition for abdominal fat, feet, head and neck, feathers and blood, were significantly affected (P <0.05) by the formulation principle adopted (Linear vs NonLinear).

Table 9 - Average values for absolute weight (grams) of carcass and body components of female broilers at 42 days of slaughter, according with the linear model (LM) and nonlinear model (NLM) formulation principle.

	42 days of age						
Tratamentes	Carcass	Abdominal fat weight	Feet	Head + neck	Viscera	Feathers	Blood
Normal LM	1930^{a}	45^{ab}	78.8^{a}	141.3^{a}	211.3^{a}	105^{a}	70^{a}
NLM +25%	1770^{a}	61.3^{a}	66.3^{ab}	133.8^{ab}	225^{a}	97.5^{a}	62.5^{a}
NLM +50%	1796^{a}	45^{ab}	62.5^{b}	135^{ab}	220^{a}	115^{a}	90^{a}
NLM -25%	1759^{a}	47.5^{ab}	66.3^{ab}	126.3^{ab}	198.8^{a}	117.5^{a}	65^{a}
NLM -50%	1895^{a}	36.3^{b}	66.3^{ab}	123.8^{ab}	211.3^{a}	112.5^{a}	63.8^{a}
Normal NLM	1785^{a}	41.3^{b}	60^{b}	120^{b}	208.8^{a}	106.3^{a}	63.3^{a}
P	0.6350	0.1697	0.1600	0.2780	0.4224	0.8060	0.3882
CV (%)	9.45	27.48	14.36	10.45	8.43	20.28	28.65

[a-b] Mean values with same letter within a column are not significantly different (P<0.05).

Table 10 - Average values for absolute weight (grams) of carcass and body components of male broilers at 42 days of slaughter, according with the linear model (LM) and nonlinear model (NLM) formulation principle.

	42 days of age						
Trataments	Carcass	Abdominal	Feet	Head + neck	Viscera	Feathers	Blood
Normal LM	2339[a]	41.3[a]	98.8[a]	163.8[a]	247.5[a]	120[a]	105[a]
NLM +25%	2243[a]	36.3[a]	96.3[a]	162.5[a]	233.8[a]	155[a]	66.3[b]
NLM +50%	2146[a]	33.8[a]	91.3[a]	140[a]	232.5[a]	107.5[a]	107.5[a]
NLM -25%	2345[a]	31.3[a]	98.8[a]	166.3[a]	256.3[a]	142.5[a]	105[a]
NLM -50%	2270[a]	31.3[a]	97.5[a]	146.3[a]	263.8[a]	150[a]	77.5[ab]
Normal NLM	2119[a]	35[a]	87.5[a]	152.5[a]	228.8[a]	137.5[a]	77.5[ab]
P	0.6936	0.9760	0.6495	0.6723	0.5930	0.3463	0.1285
CV (%)	10.84	54.80	11.83	17.15	13.49	24.57	28.51

[a-b] Mean values with same letter within a column are not significantly different (P<0.05).

Thus, abdominal fat, when expressed in absolute value (g), was significantly reduced (P <0.05) for females by 56.29% (from 120.1 g to 67.6 g, respectively for the Normal LM and Normal NLM), at 56 days of age (Table 11).

Table 11- Average values for absolute weight (grams) of carcass and body components of female broilers at 56 days of slaughter, according with the linear model (LM) and nonlinear model (NLM) formulation principle.

	56 days of age						
Trataments	Carcass	Abdominal	Feet	Head + neck	Viscera	Feathers	Blood
Normal LM	2901[a]	120.1[a]	90[a]	217.5[a]	310[a]	185[a]	87.5[a]
NLM +25%	2692[a]	98.3[ab]	82.5[a]	186.3[ab]	275[a]	180[ab]	90[a]
NLM +50%	2749[a]	73.9[bc]	91.3[a]	187.5[ab]	253.8[a]	135[b]	92.5[a]
NLM -25%	2673[a]	81.1[bc]	74.5[a]	166.3[b]	276.3[a]	157.5[ab]	97.5[a]
NLM -50%	2673[a]	97.1[abc]	90[a]	182.5[ab]	305[a]	172.5[ab]	82.5[a]
Normal NLM	2723[a]	67.6[c]	82.5[a]	180[ab]	277.5[a]	160[ab]	82.5[a]
P	0.3967	0.0116	0.7844	0.2696	0.4296	0.3274	0.8788
CV (%)	8.67	33.09	21.99	15.29	14.64	19.77	22.49

[a-c] Mean values with same letter within a column are not significantly different (P<0.05).

Table 12- Average values for absolute weight (grams) of carcass and body components of male broilers at 56 days of slaughter, according with the linear model (LM) and nonlinear model (NLM) formulation principle.

	56 days of age						
Trataments	Carcass	Abdominal fat weight	Feet	Head + neck	Viscera	Feathers	Blood
Normal LP	3455.5[a]	67.5[a]	135[ab]	211.3[b]	295[a]	190[a]	150[a]
NLM +25%	3442[a]	58.4[a]	123.8[b]	217.5[ab]	321.3[a]	185[a]	135[a]
NLM +50%	3551.5[a]	46.9[a]	135[ab]	226.3[ab]	336.3[a]	192.5[a]	127.5[a]
NLM -25%	3494.8[a]	55.3[a]	132.5[ab]	207.5[b]	336.3[a]	187.5[a]	152.5[a]
NLM -50%	3721.4[a]	63.4[a]	143.8[a]	270[a]	400[a]	212.5[a]	152.5[a]
Normal NLM	3456.8[a]	64.6[a]	127.5[ab]	223.8[ab]	323.8[a]	200[a]	125[a]
P	0.4496	0.5318	0.3233	0.2565	0.5353	0.9323	0.8685
CV (%)	8.68	39.28	9.27	16.70	22.73	23.96	30.32

[a-b] Mean values with same letter within a column are not significantly different ($P<0.05$).

There was a clear influence of the concentration of nutrients offered in normal price diets on body composition. In this way, it is directly related to the formulation principle adopted (Linear and NonLinear) and, also, the body composition is conditioned to variations in energy concentration : nutrients [9], inherent to the nonlinear principle, which because it is adopted by the spreadsheet PPFR, maintains energy density with adjustments concomitant with other nutrients [5].

The results also showed that the effects of the formulation principles were more characterized in females, mainly for the deposition of abdominal fat. Thus, the greater deposition of abdominal fat was already expected for females, due to their lower growth rate (genetic potential). Thus, excess energy is deposited as lipids in the body.

From the above, it is evident the importance of studying mathematical models and new principles of formulation that integrate the current knowledge of the use and deposition of nutrients in the body tissues of the modern broiler, mainly in protein and fat, aiming at the optimization of its deposition in the housing [11]. And in this way, to produce better quality carcasses, for increasingly demanding customers, who want a lower fat content in the products consumed [12].

4. CONCLUSION

In this study, it was observed that the ration formulation, based on the nonlinear model, corrects the distortions of the traditional system (minimum / linear cost ration), resulting in an optimal solution in terms of the energy content of the diet.

The nonlinear concept proves to be a great tool to be applied in diet formulations in order to increase the profitability of a broiler breeding.

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