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Effects of dietary energy levels on productive performance and eggs quality during the Late Phase Hy-Line Brown laying Hens

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Abstract. Diets with 2800 and 2900 kcal of ME/kg were evaluated to determine their effect on weight gain and egg quality parameters at the end of the production cycle in Hy-Line. At 74 weeks of age, 960 Hy-Line Brown hens were separated into two body weight ranges: light hens, which weighed between 1882,5- 2193,5g, and heavy hens, which weighed 2222,7-2563,7g. Data were analyzed by ANOVA and the Duncan Significant Minimum Range test was used to compare treatment means. Feed consumption, feed conversion and abdominal fat were recorded. Egg quality was determined by weight records, albumen height, egg yolk color, freshness, resistance, and thickness using the digital method with laser irradiation in the digital Egg Tester DET-600. No interactions between the diet's energy content and the hens' body weight were detected for all studied variables; therefore, only the main effects are presented. Light hens had a lower feed consumption than heavier hens (105,0 g/day *vs.* 108,1 g/day, respectively) ($P < 0.01$). The energy level of the diet did not affect this variable. At the end of the laying period, heavier hens accumulated more abdominal fat (7.9 %) compared to light hens (7.2 %) ($P < 0.01$). The weight of the eggs was affected only by the weight of the hens ($P < 0.01$). The egg yolk colour ranged from a scale of 7,2 at the lowest energy level to 6,7 at the highest energy level in the diet. In conclusion, an increase in the energy level of feed for laying hens with different body weights during the last production phase did not improve their productive performance.

Keywords: Eggs quality, Haugh units, metabolizable energy, hen production performance

Efectos del nivel de energía de la dieta sobre el desempeño productivo y calidad de huevos durante la última fase de postura de gallinas ponedoras Hy-Line Brown

Resumen. Se evaluaron dietas con 2800 y 2900 kcal de EM/kg para determinar su efecto sobre el aumento de peso y los parámetros de calidad del huevo al final del ciclo de produccion en Hy-Line. A las 74 semanas de edad, 960 gallinas Hy-Line Brown se separaron en dos rangos de peso: gallinas ligeras, que pesaban entre 1882,5 - 2193,5 g y gallinas pesadas, que pesaban entre 2222,7 - 2563,7 g. Los datos fueon analizados por ANOVA y para la comparación de medias de tratamientos se utilizó la prueba Dunkan Significant Minimun Range con una probabilidad de < 0.05 y < 0.01 tanto para los factores independientes como para la interacción del peso de la gallina y el nivel de energia de la dieta. Se colectaron datos de consumo, produccion de huevos, conversión alimenticia y grasa abdominal. La calidad del huevo se determinó mediante registros de peso, altura de albumina, color de yema de huevo, frescura, resistencia y grosor, utilizando el método digital DET-600. Los resultados muestran un menor consumo de alimentos en las gallinas livianas (105,0 g/día) en relación con las gallinas más pesadas (108,1 g/día) ($P < 0.01$). El nivel de energía de la dieta no afectó esta variable. Al final del periodo de postura, las aves más pesadas acumularon más grasa abdominal (7,9 %) respecto de las aves livianas (7,2 %) ($P < 0.01$). El peso de los huevos fue afectado únicamente por el peso de las aves ($P < 0.01$). El color de la yema del huevo varió desde una escala de 7,2 al menor nivel de energia hasta 6,7 al nivel más alto de energía de la dieta. Se concluyó que es más factible disminuir el valor energético de la dieta de aves al final del periodo de postura.

Palabras claves: Calidad de huevo, Unidades Haugh, energía metabolizable, gallinas ponedoras

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Efeitos de níveis energéticos da dieta sobre o desempenho produtivo e a qualidade dos ovos durante a fase tardia do poedeiras comerciais Hy-Line Brown

Resumo. Dietas com 2800 e 2900 kcal de EM/kg foram avaliadas para determinar seu efeito sobre o ganho de peso e parãmetros de qualidade dos ovos ao final do ciclo de produção em Hy-Line. Com 74 semanas de idade, 960 galinhas Hy-Line Brown foram separadas em duas faixas de peso: galinhas leves, pesando entre 1882,5 - 2193,5 g, e pesadas pesando entre 2222,7 - 2563,7 g. Os dados foram analisados por ANOVA e para a comparação das médias dos tratamentos foi utilizado o teste Dunkan Significant Minimum Range com probabilidade de < 0.05 e < 0.01 tanto para os fatores independentes quanto para a interação do peso da galinha e do nível energético da dieta. Foram coletados dados de consumo, produção de ovos, conversão alimentar e gordura abdominal. A qualidade dos ovos foi determinada pelos registros de peso, altura de albumina, cor da gema, frescor, forçã e espessura, utilizando-se o método digital con irradiação a laser no vovômetro Digital DET-600. Os resultados mostram um menor consumo de alimento nas galinhas mais leves (105,0 g/dia) em relação às galinhas mais pesadas (108,1 g/dia) (P < 0.01). O nível de energia da dieta não afetou essa variável. No final do período de postura, as aves mais pesadas acumularam mais gordura abdominal (7,9 %) em comparação com as aves mais leves (7,2 %) (P < 0.01). O peso dos ovos foi afetado apenas pelo peso das aves (P < 0.01). A cor da gema do ovo variou de 7,2 na menor energia até 6,7 no nível mais alto de energia da dieta. Conclui-se que é viável diminuir o valor energético da dieta das aves ao final do periodo de postura.

Palavras-chave: Qualidade do ovo, Unidades Haugh, energia metabolizável, galinhas poedeiras.

Introduction

Egg production in Latin America and Ecuador faces numerous difficulties in maintaining economic viability, which makes it necessary to explore and develop new production and marketing models that allow an efficient use of resources and particularly, efficiency in the use of energy provided by the diet (Peebles *et al*., 2000; Arenas, 2016). Several authors point out that commercial laying hens regulate feed intake according to the dietary energy level. However, the voluntary consumption of energy generally exceeds the maintenance and egg production requirements, which contribute to increase the body weight of the hen (Singh, 2005; Chan-Colli *et al*., 2007; Jiang *et al*., 2013). In this respect, Harms, Rousell and Sloan (2000), showed that the body weight of hens from four different genetic lines fed diets of 2519, 2798 and 3078 kcal ME/kg responds directly to the energy content of the diet, which is, hens that received a diet high in energy gained more weight than those hens that received a low energy diet. These findings are supported by other research, where hens fed diets equivalent to 2950 kcal ME/kg tend to gain more weight, affecting egg mass production negatively. On the contrary, the consumption of diets of 2650 kcal ME/kg affected the production of egg mass (Peebles *et al*., 2000; Sing, 2005; Pérez *et al*., 2012; Romero *et al*., 2009).

Several authors suggest that eggs quality can be enriched with certain nutrients through dietary manipulation (Petru Alexandru *et al*., 2021; Arenas, 2016), which accounts for the nutrition has also been widely accepted as a strategy to influence health and diseases of laying hens (Fuente-Martinez *et al*., 2012; Jin Wang *et al*., 2017). In this regard, egg yolk pigmentation increases linearly with the concentration of energy in the diet since xanthophyll is the main pigment responsible for yolk coloring. This pigment is highly soluble in fat, which is the reason why, by increasing the energy concentration in the diet, the level of fat increment favors xanthophyll absorption in the hen's gastrointestinal tract (Lázaro *et al*., 2003). On the other hand, it has been suggested that albumin quality decreases linearly with the increase in energy concentration of the diet (Pérez *et al*., 2012). However, supplemental fat does not affect the Haugh units of the eggs (Safa *et al*., 2008).

Due to the need to achieve good weights for an agile sale, it is necessary to adapt the rations, so it is possible to supply diets with energy levels that allow the hen to reach adequate sales weights at the end of the laying cycle and at the same time to obtain good quality eggs. The objective of this study was to determine the effect of diets with two energy levels (2800 and 2900 kcal/kg of feed) on weight gain, feed consumption, percentage of production, feed conversion and hen mortality and the effect of these diets on egg quality (weight, albumen height, yolk coloring, shell strength and thickness) in Hy-Line laying hens with weights < 2200 g and > 2200 g at the end of the productive cycle.

Materials and Methods

The experiment was carried out at 2400 m of altitude, with an average temperature of 15 ºC and 1300 mm of annual precipitation. Experimental sheds were used with a capacity of 240 cages to house 4 laying hens each, belonging to a commercial poultry company. A total of 960 hens with 74 weeks of age from the Hy-Line Brown genetic line were used, proportionally separated into two weight ranges: light hens weighed between 1882,5- 2193,5g (2071,5 71,72) and heavy hens weighed between 2222,7-2563,7g (2376,0 89,65). The weight range used in this research is explained because normally at the end of the production cycle, a diet with high energy density causes increases in energy consumption and body weight, without affecting the mass production of eggs. But that effect is apparently more pronounced in light hens than in heavy hens. In economic terms, what is expected is that the hens go to marker with adequate weights and based on diets with lower caloric density and lower cost.

Weight groups were randomly assigned to two diets (Table 1) with two energy levels (2800 and 2900 kcal/kg of feed). Each experimental unit consisted of 5 cages with 4 hens each, giving a total of 20 individuals per experimental unit, with 12 repetitions per treatment.

Table 1. Analyzed nutrient composition of the experimental diets (As a dry base).

Nutrient composition	Metabolizable energy, Kcal/kg	
	2800	2900
Crude Protein, %	15,9	15,9
Ether extract, %	5,8	7,5
Digestible Methionine, %	0,4	0,4
Digestible Lysine, %	0,7	0,7
Calcio, %	4,3	4,3

A Completely Random Design with bifactorial arrangement was used, where factor A was the initial weight of the hens and Factor B was the energy level of the diet used. Each of the repetitions was randomly distributed in the cages of the experimental house. Initial weight was recorded for 40 % of the hens per each treatment and weight was measured every 7 days until sale day at 80 weeks of age. Weight gain was determined by subtracting the weight of the corresponding week with the initial weight of the hens at week 75 of age using a digital scale graduated in grams. Each experimental unit was provided feed every day in the early hours of the morning and the next day, the remainder was weighed to define daily feed consumption.

Egg collection was performed twice a day and the production percentage was calculated by dividing the number of eggs produced by the number of hens multiplied by 100. The feed conversion was determined by dividing the feed consumption for the egg mass obtained per hen while the experiment lasted. At the beginning and the end of this research, abdominal fat percentage was evaluated for 2 % of the hens in each experimental unit. For this purpose, each hen in the sample was sacrificed, with abdominal fat removed and weighed. The result was expressed as abdominal fat weight percentage to body weight.

To determine egg quality, 12 eggs were collected weekly per treatment and were analyzed by digital method with laser irradiation using a digital Egg Tester DET 600, which allowed to determine the following variables: egg weight (g), albumen height (mm), yolk color (using the Roche colorimetric scale), freshness (Haugh units), resistance (in kgf) and thickness (mm).

The experiment was conducted as a completely randomized design with bifactorial arrange. The obtained data were analyzed by ANOVA and the comparison among means of treatments by the Duncan Minimum Significant Range test was used at two probability levels < 0.05 and < 0.01 for both the independent factors and the interaction (body weight and energy level of the diet).

Results

No interactions between the diet's energy content and the hens' body weight were detected for any studied variables; therefore, only the main effects are presented.

Body weight

Results in Table 2 show significant differences ($P < 0.01$) among weights from week 75 through week 80 in each evaluation period due to the hen weight factor. However, none of the hens group showed differences in weight between weeks.

Because of energy levels used in the diets, the weights of the hens in the different evaluation periods did not show statistical differences ($P > 0.05$), although numerically, a slight superiority was observed when using 2900 kcal/kg of feed in relation to diets with 2800 kcal EM/kg of feed. No effects of the interaction between body weight and diet energy level were found ($P > 0.05$).

Table 2. Weight (g) of Hy-Line Brown hens by the effect of body weights and two diets with different energy levels, from 75 to 80 weeks of age (end of productive cycle).

	Weight according to age (g)					
	Week					
Study factor	75	76	77	78	79	80
Layer Hen weight						
< 2200 g	2071,5[b]	2041,3[b]	2065,5[b]	2069,0[b]	2137,1[b]	2044,9[b]
> 2200 g	2376,0[a]	2335,5[a]	2339,2[a]	2357,6[a]	2416,8[a]	2315,4[a]
P value	0.000	0.000	0.000	0.000	0.000	0.000
Feed energy level						
2800 kcal	2220,7[a]	2191,0a	2196,1[a]	2206,4[a]	2264,9a	2172,8[a]
2900 kcal	2226,9[a]	2185,8a	2208,5[a]	2220,1[a]	2289,0a	2187,5[a]
P value	0.780	0.735	0.326	0.287	0.066	0.294

Average values with different letters in the same column according to the study factor; differ statistically according to Duncan test (P < 0.01).

Daily Consumption

According to Table 3, as of week 77, hens with higher weights (> 2200 g) recorded higher daily feed consumptions than hens of lower weight. Regardless of the body weight of the hens, consumption was within the range established by Hy-Line International (2016), which establishes that feed consumption from week 51 to week 90 should range between 106 and 112 g/hen/day. The diet energy level did not significantly affect feed consumption.

Table 3. Daily feed consumption (g/hen/day) of Hy-Line Brown hens because of body weights and diets with different energy levels at the end of the production cycle.

	Daily feed consumption according to age (g/hen/day)				
	Week				
Study factor	76	77	78	79	80
Layer Hen weight					
< 2200 g	100,8[a]	107,3[a]	108,3[b]	108,1[b]	105,0[b]
> 2200 g	102,6[a]	109,9[a]	111,8[b]	112,2[a]	108,1[a]
P value	0.072	0.005	0.000	0.000	0.019
Feed energy level					
2800 kcal	102,0[a]	108,7[a]	110,0[a]	110,3[a]	106,6[a]
2900 kcal	101,5[a]	108,5[a]	110,2[a]	110,0a	106,0a
P value	0.603	0.869	0.987	0.753	0.947

Average with equal letters in the same column according to the study factor, do not differ statistically according to Duncan test (P > 0.05)

Abdominal fat

Table 4 shows that in week 75, abdominal fat due to the weight of hens was not different, but at Week 80 of age, statistical differences were found, which means that the hens of greater weight tend to accumulate more abdominal fat than hens of lower weights. On the other hand, the energy level of the diet and the interaction between the body weight of hens and diets did not show differences in the accumulation of abdominal fat.

Egg weight

Egg weights (Table 5), showed statistical differences due to the initial weight of the hens, where heavier eggs are those coming from hens with weights over 2200 g.

Egg yolk color

Table 6 shows that egg color response yielded considerable variations according to the energy value of the diet used, but not due to the weight with which the hens started this research, except for the 76th week of age, where different colored egg yolks were produced. Depending on the amount of energy of the diets used, there were significant differences in the yolk color of the eggs produced at 77 and 78 weeks of age, with higher egg counts obtained from the hens that received a diet with 2900 kcal/kg compared to the eggs coming from diets with 2800 kcal. At week 80 of age, the responses were reversed, since higher grades received eggs from hens that received less energy in the diet.

Table 4. Hy-Line Brown hens' abdominal fat (%) by effect of body weight and two diets with different energy levels at the end of the productive cycle.

Study factor	Week 75	Week 80
Layer Hen weight		
< 2200 g	2,4[a]	5,6[b]
> 2200 g	2,4[a]	7,9[a]
P value	0.880	0.008
Feed energy level		
2800 kcal	2,5[a]	6,3[a]
2900 kcal	2,3[a]	7,2[a]
P value	0.539	0.180

Average with equal letters in the same column according to the study factor, did not differ statistically according to Duncan's test (P>0.05), and different letters differed statistically (P < 0.01).

Table 5. Egg weight (g) of Hy-Line Brown hens due to body weight and two diets with different energy levels at the end of the production cycle.

	Egg weight according to the age of the hen (g)				
	Week				
Study factor	76	77	78	79	80
Layer Hen weight					
< 2200 g	66,2[b]	66,7[b]	66,9[b]	67,0[b]	67,0[a]
> 2200 g	67,8[a]	67,9[a]	68,0[a]	68,3[a]	68,0[a]
P value	0.000	0.000	0.000	0.000	0.006
Feed energy level					
2800 kcal	66,9[a]	67,2[a]	67,4[a]	67,6[a]	67,2[a]
2900 kcal	67,2[a]	67,4[a]	67,5[a]	67,7[a]	67,8[a]
P value	0.336	0.383	0.711	0.831	0.082

Average with equal letters in the same column according to the study factor, did not differ statistically (P > 0.05), and different letters differed statistically (P < 0.01).

Table 6. Hy-Line Brown hens egg yolk color (Roche scale), due to body weight and two diets with different energy levels at the end of the production cycle.

	Egg yolk color according to the age of the hen (Roche scale)				
	Week				
Study factor	76	77	78	79	80
Layer hen weight					
< 2200 g	7,0[b]	7,2[a]	7,3[a]	7,2[a]	6,8[a]
> 2200 g	7,5[a]	7,5[a]	7,7[a]	7,5[a]	7,1[a]
P value	0.030	0.201	0.075	0.290	0.098
Feed energy level					
2800 kcal	7,1[a]	7,0[b]	7,1[b]	7,2[a]	7,2[a]
2900 kcal	7,4[a]	7,7[a]	7,9[a]	7,5[a]	6,7[b]
P value	0.095	0.008	0.000	0.290	0.031

Average with equal letters in the same column according to the study factor, did not differ statistically (P > 0.05), and different letters differed statistically (P < 0.01).

Discussion

In relation to body weight, the hens with higher weights gained more weight than less heavy hens. In fact, the weights recorded correspond to ideal weights as established by the Handbook for Hy-Line Brown commercial hens, with values fluctuating between 1910 and 2030 g at week 80 of age (Hy-Line International, 2016).

In effect of energy levels used in the diets, the weights of the hens in the different evaluation periods did not show statistical differences (P > 0.05). Likely, the differences between the energy levels used in this experiment were not enough to cause a significant effect on the body weight of the hens. This behavior opposes what Harms, Rousell and Sloan (2000) claimed, who reported that the body weight of hens coming from four different genetic lines, and which were fed diets of 2519, 2798 and 3078 kcal ME/kg responded directly to energy content, because hens that were fed the high energy diet gained more weight and hens that received the low energy diet gained less weight. Other authors pointed out the existence of interrelationships between diet nutrients over body weight (Olukosi and Fru-Nji, 2014; Tepox Pérez *et al*., 2012; Fuente *et al*., 2012; Gunawardana; Salas, 2013).

On the other hand, Van de Braak and Faure (2015) state that an undesired development in laying hens is the gain or loss of body weight after the peak production period of the hen since the goal is to maintain body weight gain close to zero from the peak period until the end of laying. In this way, the hen would use the raw energy from the food more efficiently to maintain a healthy body condition and for egg production.

Romero *et al*. (2009) and Pérez *et al*. (2012) point out that the extra energy allows the hen to gain weight. However, at the same time, egg production was affected since heavier and older hens require more energy to cover their maintenance needs, which leaves fewer calories available for egg formation (Fundación Española de Nutrición Animal-FEDNA, 2008; FEDNA, 2010; Singh, 2005).

In relation to feed consumption, from week 77 onwards, heavier hens (> 2200 g) showed higher consumption than lower weight hens, a behavior that can be attributed to the fact that heavier hens consume more feed to cover their nutritional needs for maintenance, compared to light hens (< 2200 g). Regardless of the body weight of the hens, feed consumption wass within the range of Hy-Line International (2016), which states that feed consumption from week 51 to week 90 usually ranges between 106 and 112 g/hen/day.

The analysis of the effect of ME diet did not show statical differences in feed consumption, which agrees with Acosta, Márquez and Angulo (2002) when evaluating different densities of hens in cages and fed with various levels of dietary energy. However, other studies indicate that the change in the energy level of diet affects consumption (Irandoust et al., 2012; López, 2013; Ravindra, 2014; Olukosi and Fru-Nji, 2014).

The hens' initial body weights and the diets' energy levels did not influence the feed conversion in the different evaluated periods, whose values fluctuated between 1,96 and 2,16. These feed conversion results align with the findings of Acosta *et al*. (2002), who found food conversions from 1,91 to 1,96 in diets containing 2000 and 2600 kcal ME/kg, respectively. Other researchers have reported contrasting results (Harms, Rousell and Sloan, 2000; Alleoni and Antunes, 2001; Acosta, Márquez y Angulo, 2002; García *et al*., 2008; Gunawardana, Roland, and Bryant, 2008; Cuca, Avila y Pro, 2009; Pérez-Bonilla *et al*., 2011; Pérez *et al*., 2012).

Regarding abdominal fat, Salas (2013) states that energy nutrition plays an important role in body composition, weight gain and hen production. According to this author, such a fact implies that an increase in the amount of energy offered during the beginnings of production, can accelerate the onset of the entry of sexual maturity of hens due to an increase in fat deposition in lighter hens. However, other authors state that as the age of the hens increases, the increase in energy of the diet does not necessarily translate into better yields during laying (Coutts and Wilson, 2007; Valkonen *et al*., 2008; Bouvarel *et al*., 2020; Wu *et al*., 2015).

It is known that the body weight of hens plays an important role in egg weight, as observed in this study. In this regard, García *et al*. (2008) claim that the main factor determining the egg's size is the body weight of the hen and it is normally expected that heavier hens produce larger eggs. On the other hand, the energy level of the diet did not influence the weight of the eggs, which contrasts with the findings of Cuca, Avila and Pro (2009), who indicate that from the nutritional point of view, egg size can be manipulated through the adequate supply of metabolizable energy and essential amino acids in the diets for laying hens, when the hens are at the beginning of the production and have a high energy requirement, the laying hen can regulate its intake by the amount of energy present in the feed (Alleoni and Antunes, 2001; Cherian, Goeger and Ahn, 2002; Gunawardana; Fuente *et al*., 2012).

The initial body weight of the hens was compared with reference values enunciated by Periago (2012), suggesting that until week 79 of age, eggs would have quality in a range of very good to acceptable, after which there would be a tendency to drop their quality at week 80. This can be explained by the fact that Haugh units are affected by storage time, temperature, age of the hen, and genetic line nutrition, among other factors (Alleoni and Antunes, 2001; De Ketelaere *et al*. 2002; Usca, 2009; Ortiz y Malo, 2009; Piraquive and García, 2014; Arena, 2016).

Apparently, the increase in energy in the diets of hens at the end of the laying cycle does not reflect a clear effect on color of egg yolk. Periago (2012) points out that the color of the egg yolk is due to 70 % to xanthophylls and 2 % to carotenes, the rest corresponds to other pigments. The large quantities of carotenes and vitamin A that appear in some feeds give a pale yolk, while the xanthophylls give very high colored buds. The pale yolks for carrying a large amount of carotenes and vitamin A are of great bromatological importance because they are more nutritious than those of high color. In fact, developing knowledge of poultry nutrition and modern biotechnology provides many measures and strategies for achieving sustainable development of the egg industry. In recent years, more and more nutritionists are exploring nutrients' additional benefits, such as health-promoting effects, rather than their traditional values (Jin Wang *et al., 2017; Yi et al*., 2021).

Conclusions

Under the conditions in which the experiment was carried out, an increase in the energy level from 2800 to 2900 kcal ME/kg of feed for laying hens with different body weights (<2000 g and >2000 g) during the last production phase did not contribute to improve the productive performance. Therefore, a decrease in the energy level of the diet during these laying phases can represent an important saving in production costs for the laying hens raising systems.

Conflict of interests: Authors declare no conflict of interest to declare

Author contributions: Conceptualization and study design: **D. Carrion and J. Grijalva**. **D. Carrion** was collected field data, **J Grijalva and F. Pazmiño** verified the underlying data, and all authors conducted the statistical analyses and have read and agreed to the published version of the manuscript.

Approval of the Animal Experimentation Committee

Due to the nature of the study and the low risk to participants and animals used in the research process, no formal Committee Ethics approval was required. All animals were treated with care and the usual farm management of samples collection was followed, without mistreatment and ensuring animal welfare.

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