Effects of energy concentration of the diet on productive performance and egg quality of brown egg-laying hens differing in initial body weight

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ABSTRACT The influence of AME_n concentration of the diet on productive performance and egg quality traits was studied in Hy-Line brown egg-laying hens differing in initial BW from 24 to 59 wk of age. Eight treatments were arranged factorially with 4 diets varying in energy content (2,650, 2,750, 2,850, and 2,950 kcal of AME_n/kg) and 2 initial BW of the hens (1,733 vs. 1,606 g). Each treatment was replicated 5 times (13 hens per replicate), and all diets had similar nutrient content per unit of energy. No interactions between energy content of the diet and initial BW of the hens were detected for any trait. An increase in energy concentration of the diet increased (linear, $P < 0.05$; quadratic $P < 0.05$) egg production, egg mass, energy efficiency (kcal of AME_n/g of egg), and BW gain ($P < 0.05$) but decreased ADFI (linear, $P < 0.001$) and feed conversion ratio per kilogram of eggs (linear, $P < 0.01$; quadratic $P < 0.01$). An increase in energy content of the diet reduced Haugh units and the proportion of shell in the egg ($P < 0.01$). Feed intake (114.6 vs. 111.1 g/hen per day), AME_n intake (321 vs. 311 kcal/hen per day), egg weight (64.2 vs. 63.0 g), and egg mass (58.5 vs. 57.0 g) were higher for the heavier than for the lighter hens ($P < 0.01$), but feed conversion ratio per kilogram of eggs and energy efficiency were not affected. Eggs from the heavier hens had a higher proportion of yolk and lower proportion of albumen ($P < 0.01$) and shell ($P < 0.05$) than eggs from the lighter hens. Consequently, the yolk-to-albumen ratio was higher ($P < 0.001$) for the heavier hens. It is concluded that brown egg-laying hens respond with increases in egg production and egg mass to increases in AME_n concentration of the diet up to 2,850 kcal/kg. Heavy hens had higher feed intake and produced heavier eggs and more egg mass than light hens. However, feed and energy efficiency were better for the lighter hens.

Key words: egg quality, initial body weight, laying hen performance, metabolizable energy

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INTRODUCTION

A major problem affecting egg production and egg weight of modern strains of laying hens is the reduced feed intake (**FI**) often observed at the onset of egg production (Leeson and Summers, 2005). A low FI results in hens that do not reach the standard BW at this age, which in turn reduces egg size during the whole egg-laying cycle (Harms et al., 1982; Leeson and Summers, 1987). Therefore, new strategies are needed to increase energy intake of the hens, especially in these countries in which consumers pay extra amounts of money for large eggs. According to Hill et al. (1956), hens adjust FI to satisfy their energy requirements, and consequently, an increase in energy concentration of the diet should reduce FI proportionally. However, changes in energy concentration of the diet have resulted in contrasting results with respect to energy intake, productive performance, and feed conversion ratio (**FCR**) of the hens (Harms et al., 2000). When the AME_n content of the diet is increased, more fat is added, and supplemental fat might improve the utilization of other components of the diet (Mateos and Sell, 1980a,b). Consequently, an increase in the AME_n content of the diet might improve nutrient utilization and egg size (Grobas et al., 1999b). Grobas et al. (1999c) reported that an increase in the AME_n content of the diet from 2,680 to 2,810 kcal/kg (a 4.8% increase) decreased FI by 5.0% but that egg production and egg mass were not affected. Similarly, Peguri and Coon (1991) reported a 5% decrease in FI and similar egg production when the AME_n of the diet was increased from 2,700 to 2,910 kcal/kg (an 8% increase). In contrast, Joly and Bougon (1997) reported a 1.3% increase in egg production, a 4.5% increase in egg mass, and a 5.7% increase in energy intake as the energy content of the diet increased from 2,200 to 2,700 kcal of AME_n/kg in brown egg-laying hens from 19 to 68 wk of age. Also, Valkonen et al. (2008) reported in Single Comb White Leghorn (**SCWL**) hens a significant in-

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crease in egg production when the AME_n content of the diet was increased from 2,340 to 2,630 kcal/kg. These data suggest that an increase in energy content of the diet might be more beneficial when low-density energy diets are used.

Body weight at the onset of egg production is a major factor influencing hen productivity. The only research conducted in the last 20 yr comparing productive performance in brown egg-laying hens varying in initial BW was that of Pérez-Bonilla et al. (2012), who reported that heavier hens had greater ADFI, egg production, and egg weight than lighter hens. However, initial BW did not affect feed conversion per kilogram of eggs or mortality, and in fact, FCR per dozen of eggs was better for the lighter than for the heavier pullets.

The effects of increasing the energy concentration of the diet on egg quality traits has not been studied in detail. Junqueira et al. (2006) did not detect any difference in Haugh units (**HU**) or eggshell quality in brown egg-laying hens fed diets varying in AME_n content from 2,850 to 3,050 kcal/kg. On the other hand, Gunawardana et al. (2008) reported similar proportions of yolk and albumen in eggs from SCWL hens fed diets varying in AME_n content from 2,750 to 3,055 kcal/kg. In contrast, Wu et al. (2005) reported that yolk weight increased and HU decreased as the AME_n of the diet increased from 2,720 to 2,955 kcal/kg. The authors have not found any published information on the effects of energy concentration of the diet on egg quality of hens differing in initial BW.

The hypothesis of the current experiment was that an increase in AME_n concentration of the diet could improve energy intake and productive performance of the hens and that the beneficial effects could be more pronounced for the light than for the heavy hens. The objectives of the research were to study the effects of energy concentration of the diet on productive performance and egg quality of brown egg-laying hens differing in initial BW from 24 to 59 wk of age.

MATERIALS AND METHODS

Husbandry, Diets, and Experimental Design

All experimental procedures were approved by the animal Ethics Committee of the Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial del Estado, 2007).

Hy-Line Brown laying hens (n = 520) were obtained from a commercial flock (Camar Agroalimentaria S.L., Toledo, Spain) and housed in an environmentally controlled barn. The hens were housed in groups of 13 in enriched cages (635 × 1,200 mm; Facco S.A., Padova, Italy) equipped with an open trough feeder and 2 nipple drinkers. The hens were weighed individually at 21 wk of age and sorted into 2 groups according to BW: heavy (1,733 ± 48 g) and light (1,606 ± 39 g). These values differed from the target weight of 1,685 ± 35 g for hens of this age (Hy-Line International, 2011). Room temperature was recorded daily throughout the experiment, with a minimum average daily value of 19 ± 3°C recorded in January (start of the experiment) and a maximum of 28 ± 3°C recorded in July. From 24 to 59 wk of age, the light program consisted of 16 h of continuous light per day.

From 21 to 24 wk of age, all hens were fed a common corn-soybean meal diet (2,750 kcal of AME/kg, 17.5% CP, and 0.46% Met). From 24 (start of the experiment) to 59 wk of age, hens were fed 1 of 4 mash diets that varied in AME_n from 2,650 to 2,950 kcal/kg but had similar nutrient content per unit of energy. For the manufacturing of the feeds, the 2 extreme diets were formulated (Fundacion Española Desarrollo Nutrición Animal, 2010) and the intermediate feeds were obtained by judicious mixing in adequate proportions of these 2 summit diets. All the diets met or exceeded the nutrient requirements for brown egg-laying hens (Fundacion Española Desarrollo Nutrición Animal, 2008). An enzyme complex that included β-glucanase and xylanase activity (Endofeed, GNC Bioferm Inc., Saskatoon, SK, Canada) was included at the dose recommended by the manufacturer in all diets. Also, a commercial pigment mixture based on canthaxantin and the ester of β-apo-8-carotenoic (Miavit Nutrición Animal S.L., Tarragona, Spain) was included in fixed amounts in these feeds. The ingredient composition and the calculated and determined nutrient content of the experimental diets are presented in Table 1.

The experimental design was completely randomized with 8 treatments arranged factorially with 4 energy levels and 2 initial BW of the hens. Each treatment was replicated 5 times, and the experimental unit was a cage with 13 hens.

Laboratory Analysis

Representative samples of the diets were ground in a laboratory mill (model Z-I, Retsch Stuttgart, Germany) equipped with a 1-mm die and analyzed for moisture by oven-drying (method 930.01), total ash using a muffle furnace (method 942.05), and nitrogen by combustion (method 990.03) using a Leco analyzer (model FP-528, Leco, St. Joseph, MI), as described by AOAC International (2000). Ether extract was determined by Soxhlet analysis after 3 *N* HCl acid hydrolysis (Boletín Oficial del Estado, 1995) and gross energy using an isoperibol bomb calorimeter (model 356, Parr Instrument Company, Moline, IL). The geometric mean diameter of the diets were determined in triplicate in 100-g samples using a Retsch shaker (Retsch, Stuttgart, Germany) equipped with 8 sieves ranging in mesh from 5,000 to 40 μm according to the methodology outlined by ASAE (1995).

Productive Performance and Egg Quality

All eggs produced were collected daily and egg weight was measured in all eggs laid during the last 2 d of each

Table 1. Ingredient composition and nutrient content of the experimental diets (% as-fed basis, unless stated otherwise)

	AME_n (kcal of AME_n/kg)			
Item	2,650	2,750	2,850	2,950
Ingredient				
Corn	6.60	6.60	6.60	6.60
Wheat	27.15	34.02	41.10	47.96
Barley	33.19	22.24	10.95	—
Soybean meal (47% CP)	21.37	23.35	25.39	27.37
Soybean oil	0.92	2.61	4.34	6.02
Monocalcium phosphate	0.86	0.95	1.04	1.13
Limestone[1]	8.97	9.27	9.59	9.91
Sodium chloride	0.30	0.31	0.32	0.33
DL-Methionine (99%)	0.14	0.15	0.17	0.18
Vitamin and mineral premix[2]	0.50	0.50	0.50	0.50
Calculated analysis[3]				
AME_n (kcal/kg)	2,650	2,750	2,850	2,950
CP	16.9	17.5	18.1	18.8
Ether extract	2.7	4.3	6.0	7.6
Lys	0.81	0.86	0.90	0.95
Met	0.44	0.46	0.48	0.50
Met+Cys	0.77	0.81	0.85	0.89
Thr	0.67	0.70	0.73	0.76
Trp	0.20	0.21	0.22	0.23
Val	0.03	0.03	0.03	0.03
Linoleic acid	1.35	2.23	3.13	4.01
Total Ca	3.66	3.80	3.94	4.08
Total P	0.68	0.69	0.71	0.73
Available P	0.44	0.46	0.48	0.49
Determined analysis[4]				
Gross energy (kcal/kg)	3,561	3,657	3,776	3,824
DM	91.5	91.7	91.6	91.9
CP	16.9	17.6	18.2	18.4
Ether extract	2.6	4.1	5.7	7.0
Total ash	12.3	12.3	12.5	12.6
GMD[5] (μm)	990	945	971	1,020
GSD[5] (μm)	±2.25	±2.23	±2.20	±2.02

[1]A total of 50% of the calcium carbonate was supplied coarsely ground (3-mm screen).

[2]Supplied per kilogram of diet: vitamin A (*trans*-retinyl acetate), 10,000 IU; vitamin D_3 (cholecalciferol), 2,000 IU; vitamin E (DL-α-tocopheryl acetate), 10 mg; vitamin B_1, 1 mg; vitamin B_2, 4 mg; vitamin B_6, 1 mg; vitamin 12 (cyanocobalamin), 15 mg; vitamin K_3, 2.5 mg; choline (choline chloride), 150 mg; nicotinic acid, 25 mg; pantothenic acid (D-calcium pantothenate), 7.5 mg; folic acid, 0.10 mg; manganese (MnO), 70 mg; zinc (ZnO), 50 mg; iron ($FeSO_4$ H_2O), 30 mg; copper ($CuSO_4$ $5H_2O$), 5 mg; iodine [$Ca(IO_3)_2$], 0.5 mg; selenium (Na_2SeO_3), 0.3 mg; canthaxantin; 2.4 g; ester of β-apo-8-carotenoic, 1.7 g (Lucanmix yellow/red, Basf, Tarragona, Spain), Endo-1.3(4)-β-glucanase (EC 3.2.1.6), 150 IU/g; Endo-1.4-β-xylanase (EC 3.2.1.8), 105 IU/g (Endofeed, GNC Bioferm, Saskatchewan, SK, Canada), Natuphos 5000 [300 FTU/kg of 6-phytase (EC 3.1.3.26), Basf Española, S.A., Tarragona, Spain].

[3]According to Fundación Española Desarrollo Nutrición Animal (2010).

[4]Analyzed in triplicate.

[5]Geometric mean diameter and log normal geometric SD.

of the nine 28-d periods. Feed intake was measured by replicate every 28 d, and mortality was recorded daily. All the hens were weighed individually at the beginning and at the end of each experimental period. From these data, hen-day egg production, egg weight, egg mass, ADFI, daily energy intake, FCR per kilogram and per dozen of eggs, energy efficiency expressed as kilocalories of AME_n per gram of egg, and BW gain were calculated by period and cumulatively.

The number of dirty, broken, and shell-less eggs was recorded daily by replicate. An egg was considered as dirty when a spot of any kind or size was detected on the shell as evaluated by 2 independent observers blind to treatment. Haugh units and yolk pigmentation were measured per replicate in 10 eggs chosen at random from eggs produced the last day at 39, 47, 55, and 59 wk of age, using a Multitester equipment (QCM System, Technical Services and Supplies, Dunnington, York, UK) as indicated by Pérez-Bonilla et al. (2011). Proportion of shell, albumen, and yolk of the eggs, and the yolk-to-albumen ratio were determined per replicate for each of the 4 periods in the same 10 eggs collected for egg quality measurements. The yolk and the shell were separated from the albumen using a paper tissue to remove any adhered material, and albumen weight was calculated by difference between egg weight and the weights of the yolk and the shell (Safaa et al., 2008).

Statistical Analysis

The experiment was conducted as a completely randomized design with 8 treatments arranged factorially, and main effects (energy level and initial BW) and their interactions were analyzed by ANOVA using the GLM procedure of SAS Institute (1990). Normal distribution of residuals and variance homogeneity of the data was tested by UNIVARIATE procedure and the Levene's test, respectively. Mortality data were analyzed by GENMOD procedure of SAS Institute (1990), using a binomial distribution. The link function was logit-transformation [$\ln(\mu/1 - \mu)$]. When the effects of energy and initial BW were significant, the Tukey test was used to make pairwise comparisons to separate treatment means. In addition, treatment sum of squares for level of energy were partitioned into linear (**L**) and quadratic (**Q**) effects. Results in tables are presented as means, and differences were considered significant at $P < 0.05$.

RESULTS

Productive Performance

No interactions between energy content of the diet and initial BW of the hens were detected for any of the traits studied, and therefore, only main effects are presented. For the entire experimental period, egg production (88.8, 91.2, 92.7, and 90.5%; L, $P < 0.01$; Q, $P < 0.01$), egg mass (56.1, 58.1, 58.8, and 58.1 g/d; L, $P < 0.01$; Q, $P < 0.01$), AME_n intake (304, 313, 316, and 324 kcal/hen per day; L, $P < 0.001$), energy efficiency (5.42, 5.39, 5.38, and 5.58 kcal of AME_n/g egg; L, $P < 0.001$; Q, $P < 0.001$), and BW gain (255, 300, 325, and 359 g; L, $P < 0.001$) increased as the AME_n content of the diet increased (Table 2). However, ADFI (115, 114, 111, and 110 g; L, $P < 0.001$), FCR per kilogram (2.05, 1.96, 1.89, and 1.89 kg/kg; L, $P < 0.001$; Q, $P < 0.01$) and per dozen of eggs (1.54, 1.48, 1.42, and 1.44 kg/dozen; L, $P < 0.01$; Q, $P < 0.01$) decreased as the energy content of the diet increased. Egg weight and mortality rate were not affected by diet. The effects of energy concentration of the diet on ADFI, egg production, egg weight, and BW gain in each of the 9 periods (28 d) of the experiment are shown in Figure 1.

Initial BW of the hens affected most productive variables studied, including egg weight, egg mass, ADFI, and FCR per dozen of eggs. For the entire experimental period, heavier hens had higher ADFI (114 vs. 111 g; $P < 0.001$) and AME_n intake (321 vs. 311 kcal/hen per day; $P < 0.001$) and produced more egg mass (58.5 vs. 57.0 g; $P < 0.01$) and bigger eggs (64.2 vs. 63.0 g; $P < 0.01$) than lighter hens. However, egg production, FCR per kilogram of eggs, energy efficiency, BW gain, and mortality rate were not affected by the initial BW of the hens. The effects of initial BW of the hens on ADFI, egg production, egg weight, and BW gain in each of the 9 periods (28 d) of the experiment are shown in Figure 2.

Egg Quality

Diet did not affect the percentage of dirty, broken, and shell-less egg, or the proportion of yolk and albumen in the egg (Table 3). However, HU (L, $P < 0.001$) and shell weight (L, $P < 0.001$) decreased and yolk

Table 2. Influence of the AME_n of the diet and initial BW of the laying hens on productive performance from 24 to 59 wk of age[1]

Item	Egg production (%)	Egg weight (g)	Egg mass (g/d)	Feed intake (g/hen per d)	FCR[2] (kg/kg)	FCR (kg/dozen)	AME intake (kcal/hen per d)	EnE[3] (kcal of AME/ g of egg)	BW gain (g)	Mortality[4] (%)
AME_n (kcal/kg)										
2,650	88.8[c]	63.1	56.1[b]	115[a]	2.05[a]	1.54[a]	304[c]	5.42[b]	255[c]	1.5
2,750	91.2[ab]	63.7	58.1[a]	114[a]	1.96[b]	1.48[b]	313[b]	5.39[b]	300[bc]	3.1
2,850	92.7[a]	63.5	58.8[a]	111[b]	1.89[c]	1.42[c]	316[b]	5.38[b]	325[ab]	0.8
2,950	90.5[bc]	64.1	58.1[a]	110[b]	1.89[c]	1.44[c]	324[a]	5.58[a]	359[a]	4.6
SEM[5]	0.59	0.27	0.46	0.69	0.010	0.010	1.9	0.030	17.3	
Initial BW										
High[6]	91.2	64.2[a]	58.5[a]	114[a]	1.95	1.49[a]	319[a]	5.45	313	1.9
Low[6]	90.5	63.0[b]	57.0[b]	111[b]	1.95	1.46[b]	310[b]	5.44	307	3.1
SEM[7]	0.42	0.19	0.32	0.49	0.008	0.007	1.4	0.021	12.2	
Effect (probability)[8]										
AME_n	***	NS	**	***	***	***	***	***	**	NS
Initial BW	NS	***	**	***	NS	***	***	NS	NS	NS
Contrast										
AME_n linear (L)	L***	NS	L**	L***	L***	L**	L***	L***	L***	NS
AME_n quadratic (Q)	Q***	NS	Q**	NS	Q**	Q**	NS	Q***	NS	NS

[a–c]Means with different superscript within each main effect are significantly different ($P < 0.05$).

[1]Data presented correspond to the means of 9 periods of 28 d each.

[2]FCR = feed conversion ratio.

[3]EnE = energy efficiency.

[4]Analyzed by GENMOD procedure.

[5]SEM (10 replicates of 13 hens each per treatment).

[6]Initial BW ± SD of 1,733 ± 48 g and 1,606 ± 39 g, for the heavy and light hens, respectively.

[7]SEM (20 replicates of 13 hens each per treatment).

[8]The interaction between AME_n and initial BW of the hens was not significant ($P > 0.05$).

**$P < 0.01$; ***$P < 0.001$.

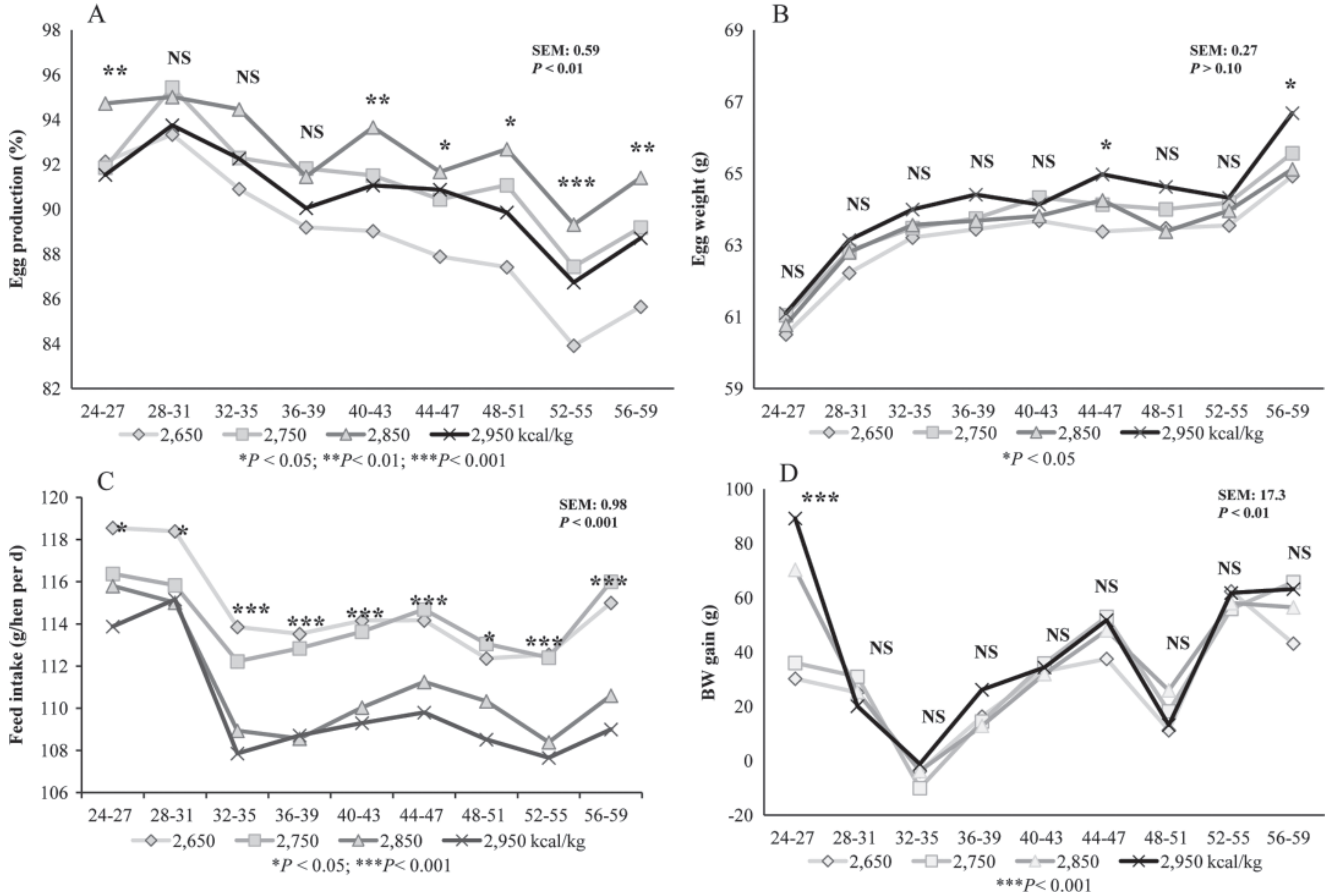

Figure 1. Effect of AME_n concentration of the diet (kcal/kg) on egg production (A), egg weight (B), feed intake (C), and BW gain (D) from 24 to 59 wk of age. The y-axis value does not start in the origin.

pigmentation (L, $P < 0.001$) increased, as the energy concentration of the diet increased. Initial BW of the hens did not affect percentage of dirty eggs, broken eggs, or shell-less. The proportion of yolk was higher ($P < 0.001$) and that of albumen lower ($P < 0.01$) for the heavy than for the light hens. Consequently, the yolk-to-albumen ratio was higher ($P < 0.001$) for the heavier hens. The effects of energy content of the diet and initial BW of the hens on HU, proportion of shell in the egg, and yolk-to-albumen ratio in the different periods studied are shown in Figures 3 and 4, respectively.

DISCUSSION

Productive Performance: AME_n Concentration of the Diet

Hens eat to satisfy their energy requirements, and therefore, an increase in the energy content of the diet should decrease FI proportionally (Hill et al., 1956). However, in the current research, an increase in the energy content of the diet from 2,650 to 2,950 kcal of AME_n/kg (a 11% increase) decreased FI by 4%, resulting in a net increase in energy intake of 7%. Bouvarel et al. (2010) reviewed a series of experiments conducted in laying hens during the last 20 yr and reported that as an average, a 10% increase in AME_n content of the diet resulted in a reduction in FI of only 5.5%, in agreement with the results of the current experiment. The data indicate that laying hens do not precisely regulate FI according to requirements and tended to overconsume energy as the AME_n of the diet increased. An increase in energy content of the diet is generally attained by increasing the amount of fat, and supplemental fat results often in higher energy intake, probably because of less dust formation and improved palatability of the diet (Grobas et al., 2001; Bouvarel et al., 2010; ISA Brown, 2011). Also, supplemental fat reduces heat increment, which in turn may increase FI under summer conditions.

Egg production increased as the AME_n concentration of the diet increased from 2,650 to 2,850 kcal/kg, but an increase to 2,950 kcal/kg did not result in any further improvement. Similar results have been reported by Mathlouthi et al. (2002) comparing diets with 2,650 and 2,750 kcal/kg. In contrast, Grobas et al. (1999c), in brown hens fed diets varying from 2,680 to 2,810 kcal of AME_n/kg, and Harms et al. (2000), in Brown and SCWL hens fed diets varying in AME_n from 2,500 to 3,100 kcal/kg, did not detect any significant difference

Table 3. Influence of the AME_n of the diet and initial BW of the laying hens on egg quality from 24 to 59 wk of age[1]

Item	Dirty eggs (%)	Broken eggs (%)	Shell-less eggs (%)	Haugh units	Yolk pigmentation[2]	Relative weight (% of the egg) Shell	Relative weight (% of the egg) Yolk	Relative weight (% of the egg) Albumen	Yolk to albumen ratio
AME_n (kcal/kg)									
2,650	6.03	1.27	0.11	88.4[a]	7.4[c]	9.7[a]	25.5	64.7	0.40
2,750	5.38	1.65	0.22	87.8[a]	7.4[bc]	9.6[a]	25.4	64.9	0.39
2,850	5.23	1.46	0.06	86.3[b]	7.6[ab]	9.6[a]	25.6	64.8	0.40
2,950	6.01	1.83	0.12	84.7[c]	7.9[a]	9.5[b]	25.6	64.9	0.40
SEM[3]	0.437	0.268	0.040	1.60	0.28	0.13	0.31	0.38	0.007
Initial BW									
High[4]	5.40	1.58	0.11	86.4	7.6	9.5[b]	25.7[b]	64.7[b]	0.40[a]
Low[4]	5.93	1.53	0.14	87.2	7.6	9.6[a]	25.3[a]	65.0[a]	0.39[b]
SEM[5]	0.309	0.190	0.030	1.13	0.20	0.09	0.22	0.26	0.005
Effect (probability)[6]									
AME_n	NS	NS	NS	***	**	**	NS	NS	NS
Initial BW	NS	NS	NS	NS	NS	*	***	**	***
Contrast									
AME_n linear (L)	NS	NS	NS	L***	L***	L***	NS	NS	NS
AME_n quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a–c]Means with different superscripts within each main effect are significantly different ($P < 0.05$).

[1]Data correspond to the average value of measurements at 39, 48, 55, and 59 wk of age.

[2]Measured using the DSM color fan according to Vuilleumier (1969).

[3]SEM (10 replicates per treatment of 13 hens each).

[4]Initial BW ± SD were 1,733 ± 48 g and 1,606 ± 39 g, for the heavy and light hens, respectively.

[5]SEM (20 replicates per treatment of 13 hens each).

[6]The interaction between AME_n and initial BW of the hens was not significant ($P > 0.05$).

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

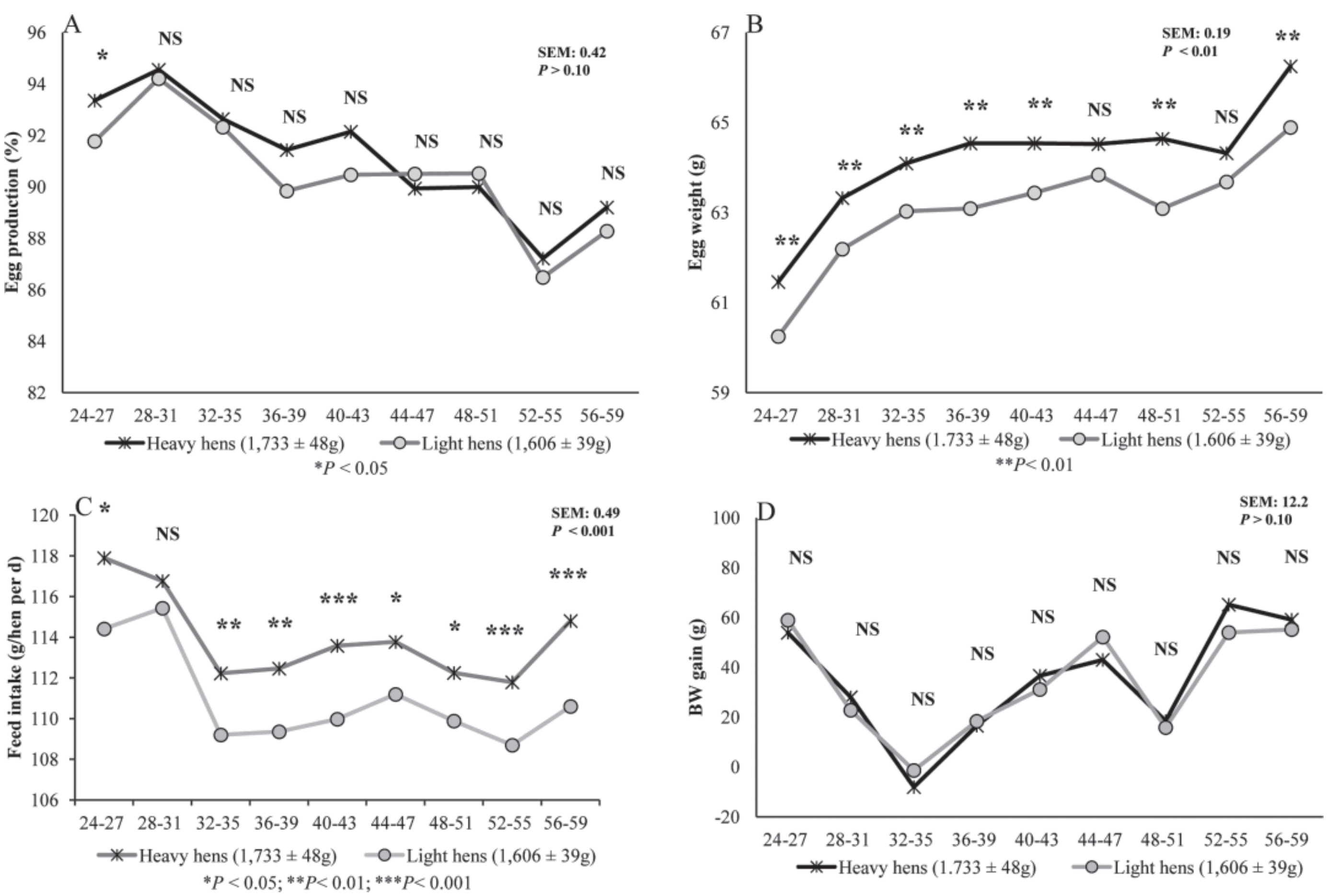

Figure 2. Effect of initial BW of the hens on egg production (A), egg weight (B), feed intake (C), and BW gain (D) from 24 to 59 wk of age. The y-axis value does not start in the origin.

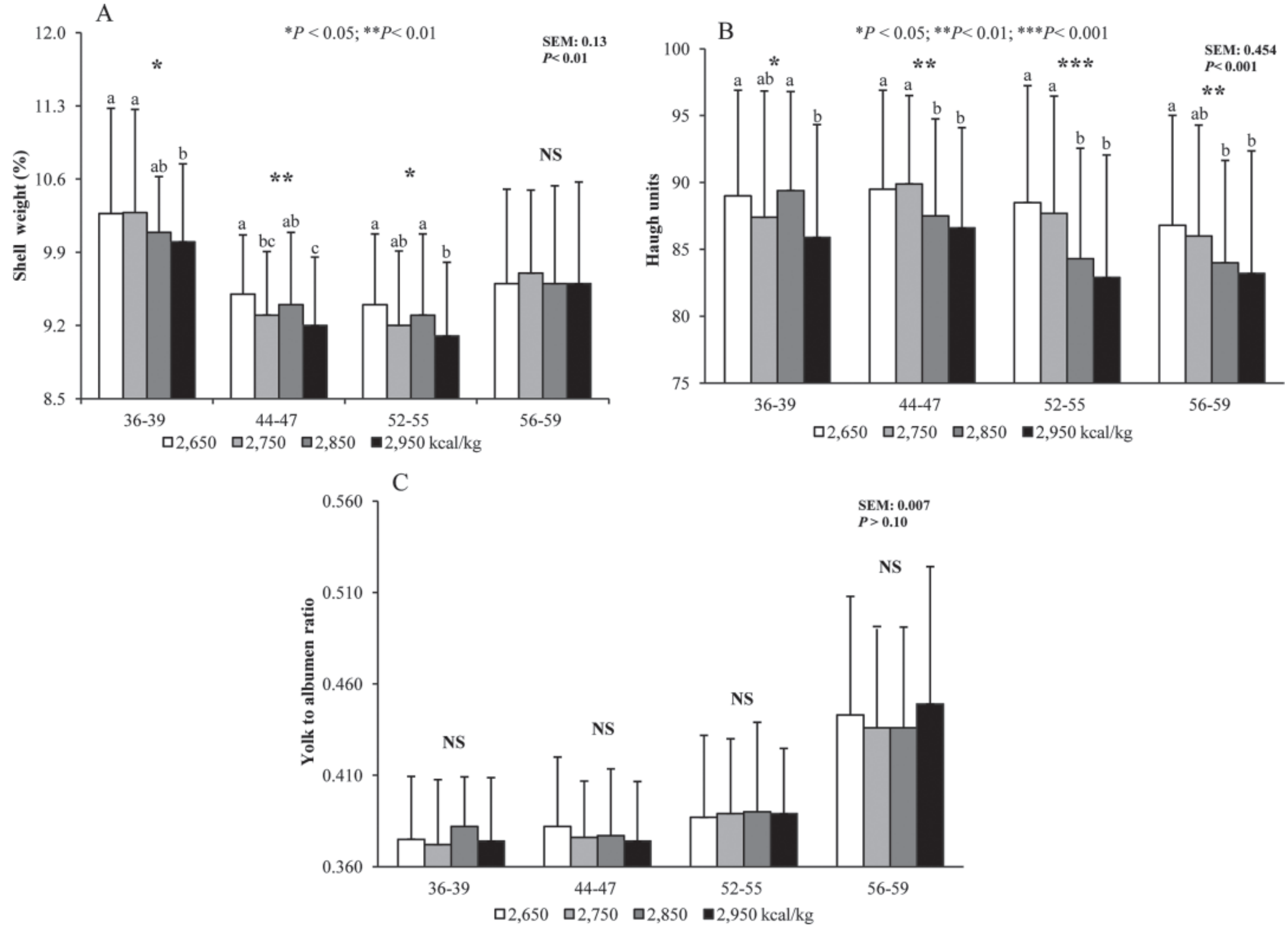

Figure 3. Effect of AME_n concentration on shell weight (A), Haugh units (B), and yolk-to-albumen ratio (C) of the eggs from 36 to 59 wk of age. The y-axis value does not start in the origin. [a–c]Means with different letters are significantly different ($P < 0.05$).

in egg production with changes in the energy content of the diet. These data support the hypothesis that an excess in energy intake caused by changes in diet composition results primarily in increases in BW gain rather than in further increases in egg mass production.

Egg weight was not affected by energy concentration of the diet, consistent with data of Grobas et al. (1999b), Çiftci et al. (2003), and Valkonen et al. (2008). Bouvarel et al. (2010) analyzed data from 11 experiments conducted for the last 20 yr and reported that egg weight increased 0.96 g per each 10 kcal of extra energy intake per day. The reasons for the discrepancies in relation to the effects of an increase in energy content of the diet on egg weight are not apparent but might depend on the fat and the linoleic acid (**LNL**) content of the diets. When the energy concentration of the diet increases, there is usually a concomitant increase in both fat and LNL content. If the LNL content of the control diet is below hen requirements, an increase in AME_n will result in higher intakes of this nutrient and in increases in egg size (Jensen et al., 1958). In the current study, the LNL content of the control diet was 1.35%, a level probably above hen requirements for maximizing egg weight (Shutze et al., 1962; Irandoust et al., 2012). Also, the level of added fat used in the diets in the current study increased from 0.92 to 6.02% as the energy content of the diet increased. Grobas et al. (1999c) reported that an increase in fat content of the diet resulted in increases in egg weight. Grobas et al. (1999b) suggested that laying hens require no more than 1.15% LNL in the diet (1.33 g/hen per day) to maximize egg weight and that when this minimal amount of LNL was met, an increase in supplemental fat resulted in further increases in egg size, irrespective of its LNL content. Therefore, the effects of increasing the energy content of the diet on egg weight might depend on the fat and LNL contents of the basal diet.

In the current research, egg mass increased as the AME_n of the diet increased from 2,650 to 2,750 kcal/kg, but a further increase to 2,850 or 2,950 kcal/kg did not result in any further improvement. These results agree with data of Keshavarz (1998), who reported similar egg mass in SCWL hens fed diets with 2,820 or 3,040 kcal of AME_n/kg. In contrast, Joly and Bougon (1997) reported in brown egg laying a 4.5% increase in egg mass as the energy content of the diet increased

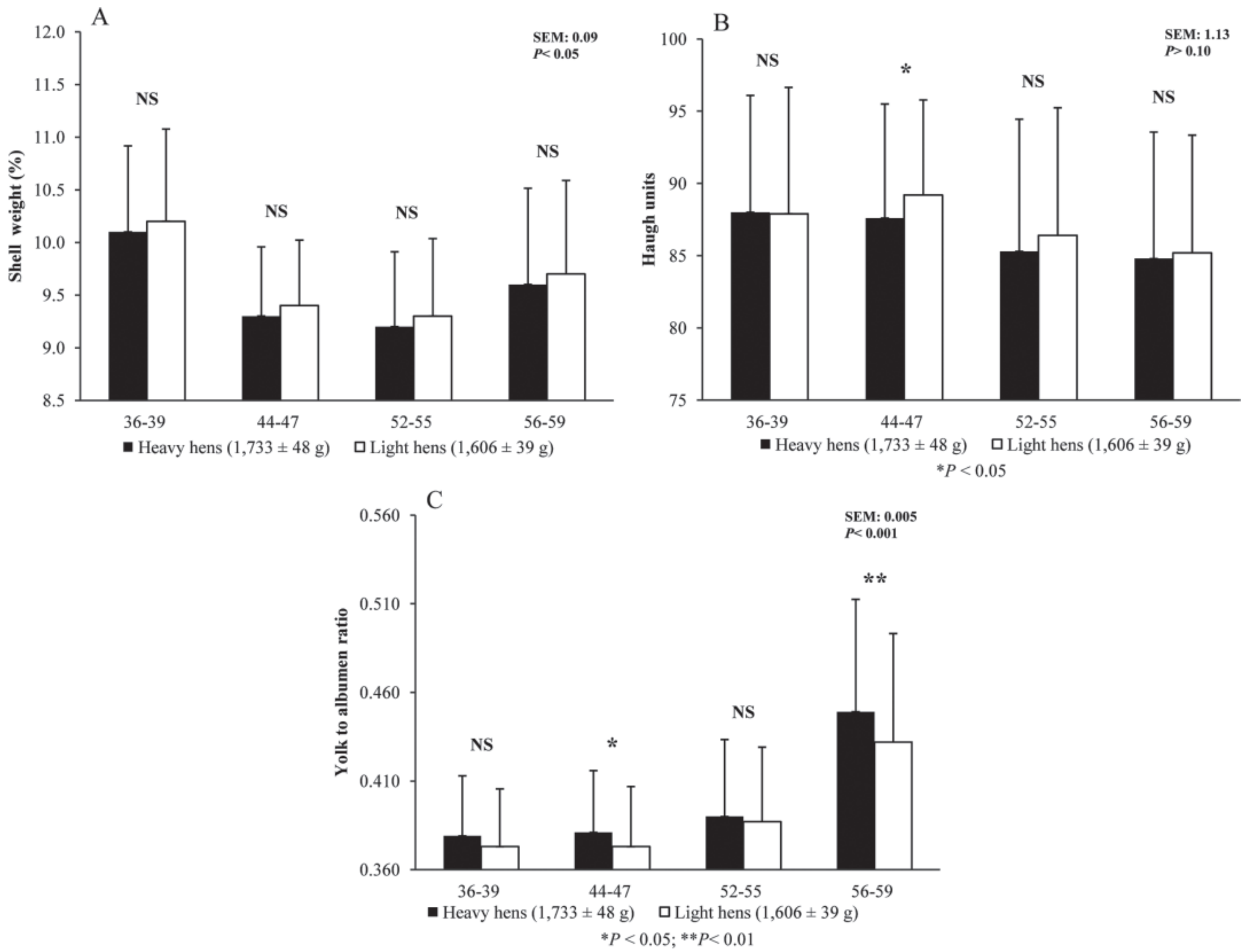

Figure 4. Effect of initial BW of the hens on shell weight (A), Haugh units (B), and yolk-to-albumen ratio (C) of the eggs from 36 to 59 wk of age. The y-axis value does not start in the origin.

from 2,200 to 2,700 kcal of AME_n/kg. Probably, hens fed very low energy diets are physically unable to eat sufficient quantities of bulky feeds to satisfy their energy requirements. Consequently, an increase in energy concentration might be more effective in improving egg mass production when low-energy diets are used.

Feed conversion ratio improved as the energy content of the diet increased, in agreement with most published reports (Grobas et al., 1999a,b; Wu et al., 2005). Hens eat feed to satisfy their energy requirements, and therefore, high AME_n diets results in improved FCR. Moreover, supplemental fat has been shown to reduce rate of feed passage, facilitating the contact between digesta and enzymes and improving digestibility and utilization of other nutrients such as the lipid and carbohydrate fractions of the diet (Mateos and Sell, 1980b, 1981). In contrast, Keshavarz (1998) reported no differences in feed efficiency in SCWL hens from 18 to 66 wk of age fed diets with 2,820 or 3,040 kcal of AME_n/kg. In the current research, hens fed the high-energy diet (2,950 kcal of AME_n/kg) had lower FI but higher energy intake than hens fed the other diets, but the excess of energy was used for increases in BW gain rather than for improvements in egg mass production. Consequently, the efficiency of converting feed energy to egg mass was hindered when the high-energy diet was used. On the other hand, hens fed the low-energy diet (2,650 kcal of AME_n/kg) consumed less energy than hens fed the other diets. Probably because of physical limitation of the gastrointestinal tract, the amount of energy consumed by the hens fed the low-energy diet was below requirements for optimal egg production, resulting in reduced egg mass.

Body weight gain increased 0.11 g/hen per day per each 100 kcal increase in AME_n concentration of the diet, a value that was below the 0.20 g reported by Grobas et al. (1999c) in brown-egg-laying hens from 22 to 65 wk of age fed diets varying in AME_n content from 2,680 to 2,810 kcal/kg, and the 0.45 g reported by Harms et al. (2000) in SCWL from 36 to 44 wk of age fed diets with 2,520 to 3,080 kcal of AME_n/kg. In contrast, Keshavarz (1998) reported an increase in BW of the hens from 20 to 66 wk of age of only 0.014, in SCWL hens fed diets varying in AME_n content from 2,820 to 3,040 kcal/kg. Modern brown-egg-laying hens respond to increases in energy content of the diets with increases in BW gain, with effects being more noticeable when high-energy diets are used.

The results suggest that modern brown-egg-laying hens might not regulate accurately FI according to energy requirements when very high or low energy diets are used. Hens fed high AME_n diets (i.e., 2,950 kcal/kg in the current trial) tended to overconsume energy with a positive effect on BWG but not in egg mass production. On the other hand, hens fed low AME_n diets (i.e., 2,650 kcal/kg in the current trial) tended to underconsume energy, with a negative effect on egg mass production.

Initial BW

The information available on the effects of initial BW of modern brown-egg-laying hens on productive performance is very limited. Heavier hens at the onset of the laying period consumed more feed and produced bigger eggs throughout the egg cycle than lighter hens (Summers and Leeson, 1983; El Zubeir and Mohammed, 1993). Bish et al. (1985) reported that heavy SCWL hens (1,377 g of BW) produced heavier eggs than medium (1,256 g of BW) and light (1,131 g of BW) hens, results that are consistent with the findings of the current research. In addition, heavier hens produced more eggs but had similar FCR per kilogram of eggs than lighter hens, confirming the results of Keshavarz (1995) and Pérez-Bonilla et al. (2012). Also, egg weight increased significantly when the initial BW of the hens was high. Keshavarz (1995) reported a 1.4-g difference in egg weight between light (1,151 g of BW) and heavy (1,333 g of BW) SCWL hens from 18 to 62 wk of age. Similarly, Pérez-Bonilla et al. (2012) reported that eggs were 2.5 g heavier in heavy (1,860 g of BW) than in light (1,592 g of BW) brown-egg-laying hens from 22 to 50 wk of age. We cannot rule out the possibility that reasons that made the hens reaching different BW at wk 21 may also have caused the differences reported during the laying period. However, in the current research pullets of the 2 BW groups were obtained from the same hatchery and were reared in the same barn under same management practices which favor the possibility that the differences observed could be ascribed to the different BW at the onset of egg production.

One of the hypotheses of the present research was that an increase in the energy concentration of the diet could be more effective in increasing energy intake and BW gain in light than in heavy hens. However, no interactions between initial BW and AME_n concentration were observed for any of the traits studied and the BW of the heavy and light hens at 50 wk was 18 and 19% higher than at 24 wk of age. These results indicate that modern brown-egg-laying hens respond similarly to increases in energy content of the diet, irrespective of the BW at the onset of egg production, data that are consistent with the report of Pérez-Bonilla et al. (2012). However, it is worthy to emphasize that a similar increase in BW might be more beneficial in light hens than in heavy hens.

Egg Quality: AME_n Concentration of the Diet

Energy concentration of the diet did not affect the percentage of dirty, broken, or shell-less eggs throughout the laying period, consistent with data of Grobas et al. (1999a). However, albumen quality decreased linearly with increases in AME concentration of the diet, in disagreement with data of Zimmermann and Andrews (1987) and Wu et al. (2005). The reasons for the discrepancies are not apparent, but in the experiment of Wu et al. (2005) diets were not balanced for CP and AA content, and the authors suggested that the decrease in HU observed was possibly due to the lower AA intake of the hens fed the high-energy diets. However, in the current experiment HU decreased with increases in AME_n concentration, in spite of all diets having similar CP and amino acid content per unit of energy. Ingredient composition might affect albumen quality (Mateos and Puchal, 1982). The main differences in ingredient composition of the 4 diets used in the current experiment were that the high-energy diets had more fat and wheat and less barley than the low-energy diets. However, Grobas et al. (1999a,b) and Safaa et al. (2008) did not observe any effect of supplemental fat on HU of the eggs, and Lázaro et al. (2003) and Pérez-Bonilla et al. (2011) did not observe any effect of the main cereal of the diet on albumen quality.

Yolk pigmentation increased linearly with increases in energy concentration of the diet, in spite of all diets having similar levels of corn and pigmenting additives. Xanthophylls, the main pigment source responsible for egg yolk color, are highly soluble in fat. As we increased the energy concentration of the diet, the level of fat increased, favoring the absorption of xanthophylls in the gastrointestinal tract of the hen (Lázaro et al., 2003).

The proportion of shell in the egg decreased linearly as the energy content of the diet increased, in agreement with the results of Junqueira et al. (2006), who reported in brown-egg-laying hens from 76 to 84 wk of age a linear decrease in egg shell proportion as the AME_n increased from 2,850 to 3,050 kcal/kg. However, Gunawardana et al. (2008) did not find any effect of energy content of the diet on egg shell proportion in SCWL fed diets varying in AME_n content from 2,750 to 3,050 kcal/kg. The level of dietary fat increased as the energy content of the diet increased, and the free added fat might form soaps with the Ca salts present in the feed, resulting in a reduction in Ca retention and in the relative weight of the shell (Atteh and Leeson, 1983, 1984). In contrast, Safaa et al. (2008) reported similar egg shell quality in the late phase of the production cycle of brown-egg-laying hens fed diets that included

1.1% or 3% of supplemental fat (soy oil and palm oil). Probably, the ratio saturated:unsaturated fatty acids in the lipid fraction of the diet might affect soap formation, fat digestibility, and final deposition of Ca in the egg shell.

Initial BW

The percentage of dirty, broken, and shell-less eggs, and the albumen quality and yolk pigmentation of the eggs were not affected by the initial BW of the hens, in agreement with data of Pérez-Bonilla et al. (2012). However, eggs from the heavy hens had higher proportion of yolk and lower proportion of albumen than eggs from the light hens. Consequently, the yolk-to-albumen ratio was higher for the heavier than for the lighter hens. The authors have not found any published report on the effects of initial BW of the hens on egg quality or on the proportion of egg components to compare with the data of the current research. Probably, heavy hens produce heavier yolks than lighter hens because of their higher FI, which may result in eggs with a higher proportion of yolk (Leeson and Summers, 2005).

In summary, an increase in energy content of the diets from 2,650 to 2,950 kcal of AME_n/kg affected performance and egg quality of the hens. Hens fed the higher energy diet (2,950 kcal of AME_n/kg) had higher energy intake than hens fed the lower energy diets, but the excess was derived to increases in BW gain rather than to improvement in egg mass production. On the other hand, hens fed the lower energy diet (2,650 kcal of AME_n/kg) had an energy intake below requirements for optimal productive performance, resulting in lower egg mass production. An increase in energy concentration of the diet reduced HU and the proportion of shell in the egg but did not affect yolk-to-albumen ratio. Heavy hens had higher FI and produced more mass of eggs than light hens, but energy efficiency was not affected. An increase in the energy content of the diet increased BW of the hens but the response was similar for all hens, irrespective of their initial BW. Heavy hens had higher yolk-to-albumen ratio than lighter hens. Productive performance was higher for heavier than for lighter hens, but the economic advantage of the heavy hens over the light hens might depend on the price difference between egg weight grades, as well as on the relative cost of feed ingredients.

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