Effect of Nutrient Density on Performance, Egg Components, Egg Solids, Egg Quality, and Profits in Eight Commercial Leghorn Strains During Phase One

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ABSTRACT This study was a 3 × 8 factorial arrangement of 3 nutrient densities (low, medium, and high) and 8 commercial Leghorn strains. The objective of this experiment was to determine the effect of increasing both dietary energy and other nutrients (amino acids, Ca, and available P) on performance, egg composition, egg solids, egg quality, and profits in 8 commercial Leghorn strains during phase 1 (from 21 to 36 wk of age). This experiment lasted 16 wk. Eight strains of hens (n = 270 of each strain) at 21 wk of age were randomly divided into 24 treatments (6 replicates of 15 birds/treatment). There were no interactions between strain and diet except for BW. Strain had a significant effect on all measured parameters except mortality, whole egg solids, and yolk color. As nutrient density increased, hens linearly adjusted feed intake to achieve similar energy intakes so that the similar quantities of dietary energy (5.8 to 5.9 kcal) were used to produce 1 g of egg. As nutrient density increased, egg mass linearly increased, and feed conversion linearly improved. Egg-specific gravity and Haugh unit linearly decreased with increasing nutrient density. There was a quadratic response of the percentage of albumen solids to the increased nutrient density. Increasing both dietary energy and other nutrient (amino acids, Ca, and available P) contents significantly increased yolk and albumen weight at the same time, resulting in a significant increase of egg weight during early egg production. Egg weight may be maximized to genetic potential by increasing both dietary energy and other nutrient (amino acids, Ca, and available P) contents during early egg production. Because egg prices and ingredient prices often change, there can be no fixed optimal nutrient density for optimal profits.

Key words: strain, energy-lysine ratio, dietary energy, lysine, total sulfur amino acid

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INTRODUCTION

Small egg size is often a problem in young hens during peak production. If egg weight can be improved quickly during peak production to reduce small- and medium-sized eggs, poultry producers will be able to improve profits, depending upon egg price, egg size, and ingredient prices. Many studies have shown that increasing dietary energy or dietary fat significantly increases early egg weight (Keshavarz, 1995; Keshavarz and Nakajima, 1995; Grobas et al., 1999; Harms et al., 2000; Bohnsack et al., 2002; Sohail et al., 2003, Wu et al., 2005b). The increased egg weight with increased dietary energy or fat is mostly due to increased yolk weight (Sell et al., 1987; Wu et al., 2005b). However, as dietary energy increases to a certain level, further increases of dietary energy do not increase egg weight more (Wu et al., 2005b). This might be explained by the decreased nutrient (protein, TSAA, and Lys) intake. As dietary energy increases, feed intake linearly decreases, resulting in the decreased nutrient (protein, TSAA, and Lys) intake (Wu et al., 2005b). Decreasing amino acid (Lys or Met) intake significantly decreases albumen weight or percentage of albumen (Prochaska et al., 1996; Shafer et al., 1998; Novak et al., 2004). Wu et al. (2005b) concluded that there might be an ideal dietary energy:protein (Lys) for optimal performance of laying hens. Increasing both dietary energy and amino acids may prevent the interfering effect of decreased nutrient (protein or amino acids) intake on egg weight so that the true effect of increasing dietary energy on egg weight could be determined. The better understanding of the effect of increasing both dietary energy and other nutrients (amino acids, Ca, and available P) may help egg producers to optimize early egg weight to improve profits, especially when a large egg price spread due to egg size exists.

Increasing only dietary energy has no significant effect on egg mass (Harms et al., 2000; Wu et al., 2005b). Increasing both dietary energy and other nutrients (amino acids, Ca, and available P) may have a significant effect on egg mass because of similar nutrient (protein or amino acids) intakes of hens fed different energy levels. In addition, feed intake can significantly affect the cost

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Table 1. Ingredients and nutrient composition of experimental diets

Ingredient	Diet 1	Diet 2	Diet 3
Corn (%)	61.14	55.36	49.13
Soybean meal (%)	27.61	29.57	31.74
$CaCO_3$ (%)	6.68	6.97	7.36
Hardshell[1] (%)	2.00	2.00	2.00
Dicalcium phosphate (%)	1.61	1.70	1.81
Poultry oil (%)	0.00	3.36	6.86
NaCl (%)	0.37	0.39	0.41
Vitamin premix[2] (%)	0.24	0.25	0.26
Mineral premix[3] (%)	0.24	0.25	0.26
DL-Met (%)	0.12	0.15	0.18
Calculated analysis			
CP (%)	18.21	18.71	19.27
ME (kcal/kg)	2,747	2,874	3,002
Ca (%)	3.86	4.00	4.18
Na (%)	0.17	0.18	0.19
Available P (%)	0.41	0.42	0.44
Met (%)	0.41	0.44	0.47
Met + Cystine (%)	0.73	0.77	0.80
Lys (%)	0.98	1.02	1.07
Dietary energy:Lys (ME/g)	281	281	281

[1]Hardshell = large particle (passing US mesh number 4 and retained by US mesh number 6) $CaCO_3$ supplied by Franklin Industrial Minerals, Lowell, Florida.

[2]Provided the following per kilogram of diet: vitamin A (as retinyl acetate), 8,000 IU; cholecalciferol, 2,200 ICU; vitamin E (as DL-α-tocopheryl acetate), 8 IU; vitamin B_{12}, 0.02 mg; riboflavin, 5.5 mg; D-calcium pantothenic acid, 13 mg; niacin, 36 mg; choline, 500 mg; folic acid, 0.5 mg; vitamin B_1 (thiamin mononitrate), 1 mg; pyridoxine, 2.2 mg; biotin, 0.05 mg; and vitamin K (menadione sodium bisulfate complex), 2 mg.

[3]Provided the following per kilogram of diet: Mn, 65 mg; I, 1 mg; Fe, 55 mg; Cu, 6 mg; Zn, 55 mg; and Se, 0.3 mg.

of production. Some studies have shown that increasing dietary energy significantly decreases feed intake (Wu et al., 2005a,b), but others have shown that there is no dietary energy effect on feed intake (Jalal et al., 2006). There is little or no research on the effect of increasing both dietary energy and other nutrients (amino acids, Ca, and available P) on egg mass, feed intake, percentage of egg components, and percentage of egg solids.

Several commercial Leghorn strains are currently used by egg producers. Because different strains have different production characteristics, egg components, egg solids, and egg quality (Wu et al., 2005b,c), some strains may be beneficial for table egg production, whereas others may be beneficial for liquid egg and dried egg processing. Few studies have been conducted to compare responses to nutrient density across strain.

The objective of this experiment was to determine the effect of increasing both dietary energy and other nutrients (amino acids, Ca, and available P) on performance, egg composition, egg solids, egg quality, and profits in 8 commercial Leghorn strains during phase 1 (from 21 to 36 wk of age).

MATERIALS AND METHODS

This study was a 3 × 8 factorial arrangement of 3 nutrient densities (low, medium, and high) and 8 commercial Leghorn strains. Ingredients and nutrient composition of experimental diets are shown in Table 1. Because feed intake normally decreases with increasing dietary energy, percentage of protein, amino acids, Ca, Na, and available P were increased as dietary energy increased to achieve a similar nutrient (protein, amino acids, Ca, Na, and P) intake so that these factors could not interfere with the effect of dietary energy. The dietary energy:lysine (281 kcal/g) was maintained the same in 3 diets. Similarly, ratios of dietary energy to TSAA, Ca, or available P were maintained constant in 3 diets.

In this experiment, 8 strains of hens (n = 2,160) at 21 wk of age were randomly assigned into 24 treatments (6 replicates of 15 birds/treatment). Hy-line W-36, Dekalb, and several experimental Bovans strains were used in this trial. The trial lasted 16 wk. Replicates were equally distributed into upper and lower cages to minimize cage level effect. Three hens were housed in a 40.6 × 45.7 cm^2 cage, and 5 adjoining cages consisted of a replicate. All hens were housed in an environmentally controlled house with temperature maintained at approximately 25.6°C (21.1°C during the night and 28.9°C during the day). Pullets were moved into the house at 18 wk of age and fed a common ration from 18 to 20 wk of age. Light was increased by 15 min/wk from 12 h/d to 16 h/d. All hens were supplied with feed and water ad libitum. Egg production was recorded daily; egg weight and feed consumption were recorded weekly; and egg-specific gravity was recorded monthly. Egg weight and egg-specific gravity were measured using all eggs produced during 2 consecutive days. Feed intake was determined by subtracting the ending feed weight of each trough (each replicate) from the beginning feed weight weekly. Egg-specific gravity was determined using 11 gradient saline solutions varying in specific gravity from 1.060 to 1.100 incremented with 0.005-unit increments (Holder and Bradford, 1979). Mortality was determined daily. Feed consumption was adjusted for mortality. Body weight was obtained by weighing 3 hens/replicate at the end of the experiment. Egg mass and feed conversion (g of feed/g of egg) were calculated from egg production, egg weight, and feed consumption.

Three eggs from each replicate were collected in the middle and the end of the experiment for measuring egg components, albumen solids, and yolk solids. Three eggs from each replicate were collected to measure whole egg solids in the middle and the end of the experiment. The procedures for measuring egg components, whole egg solids, and albumen and yolk solids were the same as those of Wu et al. (2005b). Yolk color and Haugh units were measured (3 eggs of each replicate) at the end of the experiment by egg multitester EMT-5200 (Robotmation Co. Ltd, Tokyo, Japan). Haugh unit was calculated from the records of albumen height and egg weight using the following formula: $UH = 100 \log_{10} (H - 1.7 W^{0.37} + 7.56)$, where UH = Haugh unit; H = height of the albumen; and W = egg weight.

Data were analyzed by PROC MIXED procedures of SAS (SAS Institute, 2000) for a randomized complete block with a factorial treatment design. Nutrient density and strain were fixed, whereas blocks were random. The factorial treatment arrangement consisted of 3 nutrient

Table 2. Effect of increasing both dietary energy and other nutrient (amino acids, Ca, and available P) contents on performance in 8 commercial Leghorn strains during phase 1 (from 21 to 36 wk of age)

Factor	Feed intake (g/hen per d)	Egg production (%)	Egg weight (g)	Egg mass (g egg/hen per d)	Feed conversion (g of feed/g of egg)	Egg-specific gravity (unit)	BW (kg)	Mortality (%)
Nutrient density								
Low	109.95[a]	89.80	57.76[c]	51.87[b]	2.12[a]	1.0881[a]	1.65[b]	2.09
Medium	105.72[b]	90.32	58.46[b]	52.82[a]	2.00[b]	1.0876[b]	1.68[b]	1.70
High	101.71[c]	90.22	59.08[a]	53.28[a]	1.91[c]	1.0870[c]	1.74[a]	1.81
Strain								
A	108.10[a]	88.79[b]	60.12[a]	53.38[a]	2.03[a]	1.0902[b]	1.72[a]	1.11
B	106.91[ab]	91.87[a]	58.23[b]	53.49[a]	2.00[ab]	1.0911[a]	1.72[a]	1.97
C	99.80[d]	90.43[ab]	56.74[d]	51.31[b]	1.95[b]	1.0846[f]	1.61[b]	0.74
D	108.08[a]	92.18[a]	58.12[b]	53.56[a]	2.02[ab]	1.0860[e]	1.67[ab]	3.33
E	104.89[bc]	88.22[b]	58.42[b]	51.56[b]	2.04[a]	1.0888[c]	1.73[a]	1.85
F	106.51[abc]	89.02[b]	59.86[a]	53.30[a]	2.00[ab]	1.0856[e]	1.69[ab]	2.59
G	107.87[a]	91.08[ab]	58.39[b]	53.18[a]	2.03[a]	1.0872[d]	1.70[ab]	2.22
H	104.17[c]	89.42[ab]	57.57[c]	51.48[b]	2.03[a]	1.0869[d]	1.67[ab]	1.11
Pooled SEM	1.21	2.82	0.47	0.79	0.03	0.0004	0.13	1.31
				P-value				
Main effects and interactions								
Nutrient density	0.0001	NS	0.0001	0.0029	0.0001	0.0001	0.0008	NS
Strain	0.0001	0.0002	0.0001	0.0004	0.0365	0.0001	0.0001	NS
Nutrient density × strain	NS	NS	NS	NS	NS	NS	0.0001	NS
Contrasts								
Nutrient density, linear	0.0001	NS	0.0001	0.0009	0.0001	0.0001	0.0001	NS
Nutrient density, quadratic	NS	NS	NS	NS	NS	NS	0.0518	NS

[a–f]Means within a column and under each main effect with no common superscripts differ significantly ($P \le 0.05$).

densities and 8 strains. The model used to analyze data was as follows:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + P_k + \varepsilon_{ijk}$$

where Y_{ijk} = individual observation; μ = experimental mean; α_i = nutrient density effect; β_j = strain effect; $(\alpha\beta)_{ij}$ = interaction between nutrient density and strain; P_k = effect of block; and ε_{ijk} = error component.

If differences in treatment means were detected by ANOVA, Duncan's multiple range test was applied to separate means. Contrast statements were utilized to test for nutrient density linear or quadratic effects. A significance level of $P \le 0.05$ was used for analysis.

RESULTS AND DISCUSSION

Increasing nutrient density had a significant effect on feed intake (Table 2). With increasing nutrient density, hens adjusted feed intake from 109.95 to 101.71 g/hen per day to achieve similar energy intakes (302 to 305 kcal/hen daily) so that the similar quantities of dietary energy (5.8 to 5.9 kcal) were used to produce 1 g of eggs (Table 3). These results were in agreement with that of Wu et al. (2005b), who reported that with increasing dietary energy, hens can adjust feed intake so that the same amount of dietary energy (5.8 kcal) is used to produce 1 g of eggs in Bovans and Dekalb hens. Increasing nutrient density had no effect on egg production (Table 2). There was a significant effect of strain for all parameters measured except mortality (Table 2). There were no interactions between strain and diet except for BW.

As nutrient density increased, egg weight linearly increased from 57.76 to 59.08, resulting in a 2.2% increase of egg weight (Table 2). Yolk weight linearly increased from 14.88 to 15.39 g with increased nutrient density (Table 4). Similarly, Wu et al. (2005b) reported that increasing dietary energy by the addition of poultry oil linearly increased yolk weight. Hens can use available exogenous fat as lipids for egg yolk formation during early egg production (Sell et al., 1987), and hens can deposit dietary lipid into egg yolk and change the composition of yolk lipids (Scheideler and Froning, 1996; Scheideler et al., 1998). As nutrient density increased, protein daily intake decreased, but TSAA, Lys, Ca, and available P daily intakes were similar (Table 3). Albumen weight linearly increased from 37.45 to 38.33 g as nutrient density increased (Table 4). Increasing fat content has an effect of slowing passage rate, which may lead to increased digestibility of the nutrients such as protein and amino acids (Ewan, 1991). Li and Sauer (1994) reported that apparent ileal digestibility of protein and amino acids improved as fat increased in young pigs. Similarly, Reginatto et al. (2000) concluded that increasing dietary energy improved protein utilization in broilers. The increase of albumen weight might be partially attributed to the improved nutrient (protein, TSAA, or Lys) utilization with increased dietary energy.

As dietary energy increased, egg weight significantly increased from 60.85 to 61.40 g, resulting in a 0.9% increase of egg weight in the experiment of Wu et al. (2005b). Compared with the 2.2% increase of egg weight in this experiment, the increase of egg weight in the experiment of Wu et al. (2005b) was less then 50%. The decreased amino acid intakes with increased dietary energy decreased albumen weight, which reduced the positive effect of increasing dietary energy on egg weight

Table 3. Effect of increasing both dietary energy and other nutrient (amino acids, Ca, and available P) contents on nutrient intake per hen daily in 8 commercial Leghorn strains during phase 1 (from 21 to 36 wk of age)

Factor	Energy:Lys (kcal/g)	Daily nutrient intake per hen: Energy (kcal)	Protein (g)	TSAA (g)	Lys (g)	Available P (g)	Ca (g)
Nutrient density							
Low	281	302	20.0^{a}	0.804	1.072	0.445	4.243
Medium	281	304	19.8^{b}	0.809	1.078	0.444	4.229
High	281	305	19.6^{b}	0.817	1.088	0.446	4.251
Strain							
A	281	310^{a}	20.2^{a}	0.827^{a}	1.103^{a}	0.455^{a}	4.333^{a}
B	281	307^{ab}	20.0^{ab}	0.818^{ab}	1.090^{ab}	0.450^{ab}	4.285^{ab}
C	281	287^{d}	18.7^{c}	0.763^{d}	1.018^{d}	0.420^{d}	4.001^{d}
D	281	310^{a}	20.2^{a}	0.827^{a}	1.103^{a}	0.455^{a}	4.333^{a}
E	281	301^{bc}	19.6^{b}	0.803^{bc}	1.070^{bc}	0.441^{bc}	4.204^{bc}
F	281	306^{ab}	19.9^{ab}	0.816^{abc}	1.087^{abc}	0.448^{ab}	4.272^{abc}
G	281	310^{a}	20.2^{a}	0.826^{a}	1.101^{a}	0.454^{a}	4.325^{a}
H	281	299^{c}	19.5^{b}	0.798^{c}	1.063^{c}	0.438^{c}	4.177^{c}
Pooled SEM		3.51	0.20	0.01	0.01	0.004	0.03
	Probability						
Main effects and interactions							
Nutrient density		NS	0.0376	NS	NS	NS	NS
Strain		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Nutrient density × strain		NS	NS	NS	NS	NS	NS

[a–d]Means within a column and under each main effect with no common superscripts differ significantly ($P \leq 0.05$).

(Wu et al., 2005b). These results indicate that increasing both dietary energy and other nutrients (amino acids, Ca, and available P) significantly increases yolk and albumen weight at the same time, resulting in a significant egg weight increase during early egg production. Egg weight may be maximized to genetic potential by increasing both dietary energy and other nutrient (amino acids, Ca, and available P) contents during early egg production. This may be beneficial for egg producers to increase egg weight when a large egg price spread due to egg size exists.

As nutrient density increased, egg mass linearly increased. The increased egg mass was mainly contributed from the increased egg weight (Table 2). Egg mass cannot be significantly increased, because only dietary energy increases (Wu et al., 2005b). This could be explained by a bigger increase of egg weight in this experiment, compared with the egg weight increase in the experiment

Table 4. Effect of increasing both dietary energy and other nutrient (amino acids, Ca, and available P) contents on egg components in 8 commercial Leghorn strains during phase 1 (from 21 to 36 wk of age)

Factor	Egg component weight (g): Yolk	Albumen	Shell	Egg component (%): Yolk	Albumen	Shell	Yolk:albumen
Nutrient density							
Low	14.88^{b}	37.45^{b}	5.23	25.77	65.18	9.06	0.396
Medium	15.25^{a}	37.94^{b}	5.27	26.09	64.89	9.02	0.403
High	15.39^{a}	38.33^{a}	5.36	26.07	64.86	9.07	0.402
Strain							
A	15.44^{a}	39.08^{a}	5.60^{a}	25.68^{a}	64.70^{b}	9.32^{b}	0.396^{a}
B	15.19^{ab}	37.39^{b}	5.65^{a}	26.10^{a}	64.20^{b}	9.70^{a}	0.407^{a}
C	14.74^{b}	37.13^{b}	4.87^{c}	25.97^{a}	65.43^{b}	8.59^{d}	0.397^{a}
D	15.31^{ab}	37.64^{b}	5.18^{b}	26.34^{a}	64.76^{b}	8.90^{cd}	0.407^{a}
E	15.46^{a}	37.59^{b}	5.37^{b}	26.47^{a}	64.35^{b}	9.18^{bc}	0.412^{a}
F	14.90^{ab}	39.66^{a}	5.30^{b}	24.89^{b}	66.26^{a}	8.85^{cd}	0.376^{b}
G	15.38^{a}	37.87^{b}	5.14^{b}	26.35^{a}	64.85^{b}	8.80^{cd}	0.406^{a}
H	14.97^{ab}	37.40^{b}	5.20^{b}	26.01^{a}	64.96^{b}	9.04^{bc}	0.401^{a}
Pooled SEM	0.27	0.39	0.11	0.46	0.51	0.17	0.01
	P-value						
Main effects and interactions							
Nutrient density	0.0007	0.0001	0.0589	NS	NS	NS	NS
Strain	0.0050	0.0027	0.0001	0.0013	0.0001	0.0001	0.0011
Nutrient density × strain	NS	NS	NS	NS	NS	NS	NS
Contrasts							
Nutrient density, linear	0.0002	0.0203	0.0006	NS	NS	NS	NS
Nutrient density, quadratic	NS	NS	NS	NS	NS	NS	NS

[a–d]Means within a column and under each main effect with no common superscripts differ significantly ($P \leq 0.05$).

Table 5. Effect of increasing both dietary energy and other nutrient (amino acids, Ca, and available P) contents on egg solids, Haugh units, and yolk color in 8 commercial Leghorn strains during phase 1 (from 21 to 36 wk of age)

	Solids (%)				
Factor	Whole egg	Albumen	Yolk	Haugh unit	Yolk color
Nutrient density					
Low	24.72	12.76[b]	51.13	74.75[a]	5.80
Medium	24.89	12.93[a]	51.25	74.96[a]	5.81
High	24.80	12.90[a]	51.06	70.07[b]	5.81
Strain					
A	24.38	12.69[bc]	50.35[c]	73.08[ab]	5.75
B	24.80	12.35[d]	50.39[c]	75.81[ab]	5.69
C	24.74	12.47[cd]	50.65[bc]	78.41[a]	5.58
D	24.74	12.52[cd]	50.95[abc]	71.29[ab]	5.78
E	25.08	12.94[ab]	51.04[abc]	70.31[b]	5.64
F	24.70	13.07[a]	51.25[ab]	72.40[ab]	5.86
G	24.76	12.91[ab]	51.30[ab]	72.96[ab]	5.69
H	24.86	13.02[a]	51.73[a]	71.80[ab]	5.94
Pooled SEM	0.25	0.09	0.21	2.93	0.24
	P-value				
Main effects and interactions					
Nutrient density	NS	0.0200	NS	0.0012	NS
Strain	NS	0.0001	0.0001	0.0237	NS
Nutrient density × strain	NS	NS	NS	NS	NS
Contrasts					
Nutrient density, linear	NS	0.0066	NS	0.0018	NS
Nutrient density, quadratic	NS	0.0014	NS	0.0406	NS

[a–d]Means within a column and under each main effect with no common superscripts differ significantly ($P \leq 0.05$).

of Wu et al. (2005b). Increasing nutrient density linearly improved feed conversion from 2.12 to 1.91, resulting in a 9.9% improvement of feed conversion (Table 2). Wu et al. (2005b) reported that only increasing dietary energy linearly improved feed conversion by 7.9%. Therefore, increasing both dietary energy and other nutrients (amino acids, Ca, and available P) obtained more improvement in egg mass and feed conversion than just increasing dietary energy. This might be because other nutrients became limiting, because only dietary energy increased, resulting in less feed intake.

Egg-specific gravity linearly decreased with nutrient density, probably because egg weight significantly increased (Table 2). Sohail et al. (2003) reported that the decrease of egg-specific gravity was due to increased egg weight caused by increased fat. There was an interaction between strain and diets on the BW of hens. Increasing nutrient density linearly increased hen BW in strains A, F, and G but had no effect on hen BW of other strains (Table 2). Increasing only dietary energy had no effect on BW of Bovans and Dekalb hens during phase 1 (Wu et al., 2005b). Novak et al. (2004) reported that increasing Lys intake significantly increased hen weight gain. These results indicate that increasing both dietary energy and other nutrient (protein or amino acids) contents significantly increased hen BW of some strains.

Table 6. Influence of nutrient density and poultry oil price on profits[1] from 21 to 36 wk of age

	Nutrient density		
Item	Low	Medium	High
	Returns[4]($/dozen)		
High poultry oil price ($0.40/kg)			
High egg price[2]	0.264	0.265	0.261
Low egg price[3]	0.112	0.106	0.101
Low poultry oil price ($0.22/kg)			
High egg price	0.264	0.273	0.278
Low egg price	0.112	0.113	0.109

[1]Corn = $0.10/kg; soy = $0.19/kg; $CaCO_3$ = $0.03/kg; hard shell = $0.03/kg; dicalcium phosphate = $0.27/kg; NaCl = $0.06/kg; vitamin premix = $2.67/kg; mineral premix = $0.59/kg; DL-Met = $2.59/kg.

[2]High Urner Barry egg price: jumbo size = $1.05; extra large size = $1.01; large size = $0.97; medium size = $0.75; and small size = $0.54.

[3]Low Urner Barry egg price: jumbo size = $0.83; extra large size = $0.80; large size = $0.78; medium size = $0.65; and small size = $0.54.

[4]Returns (R) were calculated using the equation: R = UBEP − NR − PC − FdC, where UBEP = Urner Barry egg price; NR = nest run into package product delivered; PC = production cost; and FdC = feed cost, as described by Roland et al. (1998, 2000).

Increasing nutrient density had no significant effect on shell weight, percentage of yolk, percentage of albumen, and percentage of shell (Table 4). Because both yolk weight and albumen weight increased as nutrient density increased, yolk:albumen did not change with increased nutrient density (Table 4). Albumen weight of strain F was similar to that of strain A but was significantly higher than that of the other strains (Table 4). Strain F had the lowest yolk:albumen among 8 strains.

Increasing nutrient density had no effect on the percentage of whole egg solids, percentage of yolk solids, and yolk color (Table 5). There was a quadratic response of percentage of albumen solids to the increased nutrient density. Novak et al. (2004) reported that increasing Lys intake increased the percentage of albumen solids. Haugh unit is a measure of the freshness of an egg. The Haugh unit of hens fed the high nutrient density was significantly lower than that of hens fed other nutrient densities, possibly because of the higher egg weight of hens fed the high nutrient density. Based on Haugh unit formula, Haugh unit has a negative relationship with egg weight. Strain had a significant effect on albumen solids, yolk solids, and Haugh unit but had no effect on whole egg solids and yolk color (Table 5).

An economic feeding and management program developed by Roland et al. (1998, 2000) was used to calculate profits of different nutrient densities at different poultry oil prices and egg prices (Table 6). When poultry oil price was high and egg price was high, maximum profit per dozen eggs was obtained in the hens fed the medium nutrient density diets. When poultry oil price was high and egg price was low, maximum profit per dozen eggs was obtained in the hens fed the low nutrient density diets. Similarly, because poultry oil price was low, maximum profits per dozen eggs was obtained in the hens fed different nutrient densities, according to different egg prices. Therefore, because feed ingredient prices and egg price often vary, there can be no fixed ideal nutrient density for optimal profits during phase 1 (wk 21 to 36). Poultry producers may need to apply some economic feeding and management software to determine the diets for optimal profits.

In conclusion, there were no interactions between strain and diet except for BW. Strain had a significant effect on all measured parameters except mortality, whole egg solids, and yolk color. As nutrient density increased, hens linearly adjusted feed intake to achieve similar energy intakes (302 to 305 kcal/hen daily) so that the similar quantities of dietary energy (5.8 to 5.9 kcal) were used to produce 1 g of eggs. As nutrient density increased, egg mass linearly increased and feed conversion linearly improved. Egg-specific gravity and Haugh unit linearly decreased with increasing nutrient density. There was a quadratic response of percentage of albumen solids to the increased nutrient density. Increasing both dietary energy and other nutrient (amino acids, Ca, and available P) contents significantly increased yolk and albumen weight at the same time, resulting in a significant increase of egg weight during early egg production. Egg weight may be maximized to genetic potential by increasing both dietary energy and other nutrient (amino acids, Ca, and available P) contents during early egg production. Because egg prices and ingredient prices often change, there can be no fixed optimal nutrient density for optimal profits.

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