Effects of feeding diets varying in energy and nutrient density to Hy-Line W-36 laying hens on production performance and economics,[1]

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ABSTRACT The objectives of this study were to evaluate the effects of feeding 5 different energy and nutrient dense diets to Hy-Line W-36 hens on long-term performance and economics. A total of 480 19 wk old Hy-Line W-36 Single Comb White Leghorn hens were weighed and randomly allocated to 6 replicate groups of 16 hens each (2 adjacent cages containing 8 hens per cage, 60.9 × 58.4 cm) per dietary treatment in a randomized complete block design. The hens were fed 5 treatment diets formulated to contain 85, 90, 95, 100, and 105% of the energy and nutrient recommendations stated in the 2009 Hy-Line Variety W-36 Commercial Management Guide. Production performance was measured for 52 wk from 19 to 70 wk age. Over the course of the trial, a significant increasing linear response to increasing energy and nutrient density was seen for hen-day egg production, egg weight, egg mass, feed efficiency, energy intake, and body weight (BW). Feed intake showed no significant linear level response to increasing energy and nutrient density except during the early production cycle. No consistent responses were noted for egg quality, percent yolk, and percent egg solids throughout the study. Significant linear responses due to energy and nutrient density were seen for egg income, feed cost, and income minus feed cost. In general, as energy and nutrient density increased, egg income and feed cost per hen increased, but income minus feed cost decreased. Overall, these results indicate that feeding Hy-Line W-36 hens increasing energy and nutrient-dense diets will increase egg production, egg weight, egg mass, feed efficiency, energy intake, BW, egg income, and feed cost, but decrease egg income minus feed cost. However, these benefits do not take effect in early production and seem to be most effective in later stages of the production cycle, perhaps "priming" the birds for better egg-production persistency with age.

Key words: laying hens, low-energy diets, egg production

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INTRODUCTION

Outside the Midwest United States, high-energy feed ingredients such as corn grain and vegetable oil are relatively expensive, meaning that low-energy diets are often fed. While low-energy diets may not appear to supply sufficient energy to laying hens, hens can regulate their feed intake rate to maintain energy intake (Harms et al., 2000; Leeson et al., 2001; Wu et al., 2005, 2007). In this way, hens will consume more of a low-energy diet than of a high-energy diet, thus ensuring that the calories consumed are similar with either diet. Accordingly, the percentage of nutrients, such as amino acids or phosphorous, can be lower in a low-energy diet than in a high-energy diet, yet still ensure adequate nutrient consumption due to the changes in feed intake. However, other research has suggested that hens are not accurate in adjusting feed intakes (Morris, 1968; Jalal et al., 2007). Yet, low-density diets are attractive to producers outside the Midwestern United States due to their lower purchase price, and often, mainly low-density commercial laying-hen diets are available from independent feed mills outside the United States (K. Bregendahl, Hy-Line International, personal communication).

Early work by Harms et al. (2000) demonstrated that Hy-Line W-36 hens responded to a low-energy diet (2,519 kcal ME/kg) by increasing feed intake. Using Babcock BV300 hens, Rao et al. (2104) demonstrated that increased feed intake occurred (21 to 72 wk age) when the birds were fed a diet containing 2,399 vs. 2,550 vs. 2,700 kcal/kg ME, respectfully. However, more recently, Jalal et al. (2007) showed that Hy-Line W-36 hens did not increase feed intake when fed a low-energy diet (2,810 vs. 2,900 kcal ME/kg). Modern strains of laying hens, such as the Hy-Line W-36, only have a

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limited capability to increase their feed intake to ensure adequate energy and nutrient intake. This is due to the characteristic low feed intake and increased feed efficiency of this strain of bird. While low-energy and nutrient dense diets are less expensive to purchase, they will not ensure optimal egg production if hens do not adjust their feed intake. If hens do not have the capacity to increase their feed intake in order to consume enough of the nutrients they require, egg production can suffer. This may result in reduced returns due to decreases in egg incomes stemming from reductions in egg numbers and/or egg weights. On the other hand, the purchase price of low-energy and nutrient dense diets can be substantially lower than high-density diets and, if effective in maintaining long-term egg production and egg weight, can result in increased returns for the producer. Thus, feeding low-energy and nutrient dense diets to laying hens may result in improved returns due to a lower cost of those diets. However, it has been shown that the increased efficiency of birds fed on high-energy and nutrient dense diets can offset the higher cost of the feed (Leeson and Summers, 2009).

Given this background, the hypothesis of this study was that Hy-Line W-36 laying hens can respond to lower energy and lower nutrient density diets, by increasing feed intake to maintain energy and nutrient consumption that will support maximal egg production. Therefore, the objectives of this study were to measure egg production and the economic effects of feeding diets of 5 different energy and nutrient contents.

MATERIALS AND METHODS

All animal care procedures were approved by the university's Institutional Animal Care and Use Committee. A total of four hundred eighty 19-week-old Hy-Line W-36 Single Comb White Leghorn hens were used in the experiment. The chicks were transported to the poultry research farm at 1 d age and were brooded and reared on the floor in a grow-out building for 17 wk, upon which they were moved to a fan-ventilated cage laying-hen facility of commercial design. At this time, they were fed a prelay diet [17.0% crude protein (CP), 2,951 kcal/kg nitrogen-corrected apparent metabolizable energy (AME_n), 2.5% Ca, and 0.48% available phosphorus] and allowed to acclimate for 1 wk. At the end of 18 wk age all hens were weighed and assigned to treatments in a randomized complete block design, with location within house and initial body weight (BW) as blocking criteria. Hens were housed 8 hens/cage (60.9 × 58.4 cm; 69 in^2/hen) to simulate industry practices and 2 adjacent cages of 8 hens each served as the experimental unit. Six replicate groups of 16 hens were each randomly assigned to each of the 5 treatment diets. All hens were fed the experimental diets from 19 to 70 wk age. At the end of 29 wk age, hens fed the 85% treatment were fed a new batch of feed; however, it was discovered at 32 wk age that the analyzed Na content of this feed was only 0.04%. Thus, salt was inadvertently omitted from the diet of the 85% treatment from 30 to 32 wk age, during which time the egg production quickly fell below 50% and the hens were switched to the 100% treatment (control). Data from this group were not considered in the statistical analysis after 26 wk age.

Hens were managed according to the guidelines in the Hy-Line Variety W-36 Commercial Management Guide (2009) and had free access to feed and water at all times. The guide recommends formulating the diet such that the hens consume an absolute amount of nutrients per day, varying the dietary energy and nutrient concentrations according to feed intake. For 19-week-old hens, formulating for a feed intake of 82 g (18 lb/d per 100 hens) is recommended. Thus, in phase 1, the control diet (100% treatment) was formulated to contain 2,950 kcal/kg AME_n and to supply 4.0 g/d calcium, 500 mg/d available phosphorus, 180 mg/d sodium, and 805 mg/d digestible lysine (other amino acids based on the ideal acid ratios calculated from the management guide; there were no restrictions on the dietary CP content) for a feed intake of 82 g/d. This diet, therefore, contained 4.88% calcium, 0.61% available phosphorus, 0.22% sodium, and 0.98% digestible lysine. The other dietary treatments were formulated to supply similar absolute amounts of nutrients (in grams per day), but for feed intakes varied by 5% (i.e., 94, 90, 86, and 78 g/d for the 85, 90, 95, and 105% treatments, respectively). There is no recommendation for a daily energy intake (in kilocalories/day) in the Hy-Line W-36 management guide, so the dietary energy concentrations were instead varied in 67 kcal/kg increments to range from 2,750 kcal/kg in the 85% treatment (based on the lowest observed energy concentrations in first-phase diets for Hy-Line W-36; K. Bregendahl, personal observation) to 2,950 kcal/kg in the 100% treatment (i.e., the dietary energy concentration recommended in the Hy-Line W-36 management guide), and by extension, to 3,017 kcal/kg in the 105% treatment. This approach resulted in equally spaced energy and nutrient densities among dietary treatments, and was repeated for recommended energy and absolute daily nutrient consumption in phases 2 and 3 (Tables 1 to 3). All diets were formulated on a least-cost basis using corn grain, soybean meal, wheat middlings, corn distiller's dried grains with solubles, soybean oil, and/or soybean hulls, to mimic industry practices, using feed-ingredient prices from a local commercial feed mill. Phase 1 diets were fed from 19 to 26 wk age (8 wk), phase 2 diets were fed from 27 to 32 wk age (6 wk), and phase 3 diets were fed from 33 to 70 wk age (38 wk).

Egg Production and Performance

All hens were weighed at the beginning of the experiment at 19 wk age, as well as when switched from phase 1 to phase 2, phase 2 to phase 3 diets, and at the conclusion of the experiment at 70 wk age.

Table 1. Composition of the experimental diets fed during phase 1 of the laying period[1].

	Nutrient density (%)[2,3]				
Ingredient	Eighty-five percent treatment	Ninety-percent treatment	Ninety-five percent treatment	One hundred percent treatment	One hundred five percent treatment
Corn	53.46	51.44	45.59	41.75	35.50
Soybean meal (48% CP)	25.70	27.70	30.73	33.88	37.14
Pork meal (50% CP)	5.00	5.00	5.00	5.00	5.00
Corn DDGS[4]	4.28	2.00	2.00	—	—
Soybean oil	0.48	2.15	4.29	6.25	8.48
Calcium carbonate[5]	9.26	9.66	10.13	10.61	11.16
Dicalcium phosphate	0.93	1.08	1.24	1.44	1.59
NaCl	0.30	0.34	0.36	0.39	0.42
Vitamin mix[6]	0.20	0.20	0.20	0.20	0.20
Mineral mix[7]	0.15	0.15	0.15	0.15	0.15
DL-Methionine	0.19	0.23	0.25	0.28	0.31
Larvadex	0.05	0.05	0.05	0.05	0.05
Calculated composition					
CP (%)	19.66	19.89	20.87	21.56	22.62
AME_n (kcal/kg)	2,750	2,817	2,884	2,950	3,017
Crude fat (%)	3.49	4.84	6.80	8.41	10.44
Calcium (%)	4.24	4.43	4.65	4.88	5.13
Phosphorus, nonphytate (%)	0.53	0.55	0.58	0.61	0.64
Sodium (%)	0.19	0.20	0.21	0.22	0.23
Digestible lysine (%)	0.92	0.95	1.01	1.07	1.14
Digestible methionine (%)	0.47	0.50	0.53	0.56	0.60
Digestible Met + Cys (%)	0.72	0.75	0.79	0.82	0.87
Analyzed composition (%)					
CP	19.74	19.90	20.68	19.99	21.20
Crude fat	3.06	4.04	6.20	7.19	8.26
Calcium	3.87	6.40	4.88	8.62	6.36
Total phosphorus	0.75	0.72	0.80	0.73	0.84
Sodium	0.15	0.21	0.22	0.15	0.20
Dry matter	88.80	88.90	89.00	89.90	89.10

[1]Phase 1 treatment diets were fed from 19 to 26 wk age (8 wk).

[2]Percentage of recommended nutrient density.

[3]The feed costs per ton for treatments 85 to 105% were $279.80, $307.00, $341.20, $376.48, and $410.10, respectively.

[4]DDGS = Distiller's dried grains with solubles.

[5]Sixty-five percent of the calcium carbonate was supplied in particle sizes over 2 mm.

[6]Provided per kilogram of diet: vitamin A from vitamin A acetate, 4,400 IU; cholecalciferol, 1,000 IU; vitamin E from α-tocopheryl acetate, 11 IU; vitamin B_{12} 0.011 mg; riboflavin, 4.4 mg; d-pantothenic acid, 10 mg; niacin, 22 mg; menadione sodium bisulfate complex, 2.33 mg.

[7]Provided per kilogram of diet: manganese, 75 mg from manganese oxide; iron, 75 mg from iron sulfate; zinc, 75 mg from zinc oxide; copper, 5 mg from copper sulfate; iodine, 0.76 mg from ethylene diamine dihydroiodide; selenium, 0.1 mg from sodium selenite.

Egg production and mortality were recorded daily, whereas feed consumption was measured every 2 wk as feed disappearance. Eggs were collected over a 48 h period and weighed every 2 wk, for determination of egg weight and egg grades.

When hens were 27 wk age and every 4 wk thereafter, a maximum of 30 eggs/replicate laid in a 48 h period were collected and transported to Hy-Line International Egg Quality Laboratory in Dallas Center, Iowa, for determination of shell breaking strength, egg weight, albumen height, shell color, yolk weight, and Haugh units. Haugh units were calculated according to Wu et al. (2007). Egg shell color was determined using a custom, proprietary index that combines the three parameters (L, a, b) of the Minolta Chroma Meter system. The lesser the index values the whiter the shell color. Eggs collected from a second 24 h period when hens were 27 wk age, and every 8 wk thereafter, were weighed and percent solids were measured at the University of Illinois according to Wu et al. (2005). Seven eggs per replicate were collected 6 times at 31, 38, 46, 54, 62, and 69 wk age, and percent yolk, yolk solids, albumen solids, and whole egg solids were determined.

Economics

Economics were evaluated as the income over feed cost, calculated from the cost of feeding the hens and the price obtained for the eggs. Egg income was calculated every 2 wk when eggs were graded. A ratio of the total number of eggs laid in 2 wk over the total number of eggs laid over 2 consecutive days of collection was used to provide an estimate of the number of eggs laid in each USDA size category over 2 wk/hen. Urner-Barry egg prices (Urner Barry's Price–Current (2009, 2010) from the weeks corresponding to the start of each phase when hens were 20, 27, and 34 wk age) were used to calculate egg income for each phase. These egg prices were $1.06, $0.99, $0.96, $0.76, and $0.64 for phase 1; $1.06, $1.02, $0.99, $0.87, and $0.68 for phase 2; and $1.30, $1.34, $1.34, $1.10, and $0.88 for phase 3 for jumbo, extra-large, large, medium, and small eggs, respectively. The percent of jumbo, extra-large, large,

Table 2. Composition of the experimental diets fed during phase 2 of the laying period[1].

	Nutrient density (%)[2,3]				
Ingredient	Eighty-five percent treament[4]	Ninety percent treatment	Ninety-five percent treatment	One hundred percent treatment	One hundred five percent treatment
Corn	51.68	57.07	54.45	50.65	45.07
Soybean meal (48% CP)	21.77	23.05	25.66	28.71	31.46
Wheat middlings	5.00	—	—	—	—
Pork meal (50% CP)	3.81	5.00	5.00	5.00	5.00
Corn DDGS[5]	7.50	4.23	2.00	—	—
Soybean oil	—	0.17	1.88	3.84	5.96
Calcium carbonate[6]	8.59	8.80	9.20	9.63	10.18
Dicalcium phosphate	0.85	0.83	0.98	1.18	1.29
NaCl	0.26	0.28	0.21	0.34	0.37
Vitamin mix[7]	0.20	0.20	0.20	0.20	0.20
Mineral mix[8]	0.15	0.15	0.15	0.15	0.15
DL-Methionine	0.14	0.17	0.22	0.24	0.27
Larvadex	0.05	0.05	0.05	0.05	0.05
Calculated composition					
CP (%)	18.63	18.67	19.15	19.80	20.68
AME_n (kcal/kg)	2,711	2,777	2,844	2,910	2,977
Crude fat (%)	3.34	3.28	4.66	6.29	8.22
Calcium (%)	3.86	4.04	4.23	4.44	4.68
Phosphorus, nonphytate (%)	0.48	0.51	0.53	0.56	0.58
Sodium (%)	0.17	0.18	0.19	0.20	0.21
Digestible lysine (%)	0.84	0.86	0.90	0.96	1.02
Digestible methionine (%)	0.40	0.44	0.48	0.51	0.54
Digestible methionine + cysteine (%)	0.65	0.68	0.72	0.75	0.79
Analyzed composition (%)					
CP	19.57	18.68	20.78	18.95	20.85
Crude fat	2.95	2.93	3.65	4.71	6.95
Calcium	4.46	4.98	4.79	7.00	6.30
Total phosphorus	0.67	0.72	0.69	0.66	0.75
Sodium	0.13	0.18	0.16	0.16	0.23
Dry matter	88.80	88.50	88.80	89.60	89.00

[1]Phase 2 treatment diets were fed from 27 to 32 wk age (6 wk).

[2]Percentage of recommended nutrient density.

[3]The feed costs per ton for treatments 85 to 105% were $248.20, $266.60, $295.10, $326.90, and $359.70, respectively.

[4]At the end of 29 wk age, a new batch of feed was mixed and fed to birds on this treatment. It was discovered that the Na content was 0.04% fed as is. Thus, hens on this treatment received this diet without salt added for the last 3 wk of this phase (30 to 32 wk age).

[5]DDGS = Distiller's dried grains with solubles.

[6]65% of calcium carbonate was supplied in particle sizes over 0.14 mm.

[7]Provided per kilogram of diet: vitamin A from vitamin A acetate, 4,400 IU; cholecalciferol, 1,000 IU; vitamin E from α-tocopheryl acetate, 11 IU; vitamin B_{12} 0.011 mg; riboflavin, 4.4 mg; d-pantothenic acid, 10 mg; niacin, 22 mg; menadione sodium bisulfate complex, 2.33 mg.

[8]Provided per kilogram of diet: manganese, 75 mg from manganese oxide; iron, 75 mg from iron sulfate; zinc, 75 mg from zinc oxide; copper, 5 mg from copper sulfate; iodine, 0.76 mg from ethylene diamine dihydroiodide; selenium, 0.1 mg from sodium selenite.

medium, and small eggs laid over 2 d were multiplied by their respective Urner-Barry Midwest 5 day average price quote, added together, and multiplied by the ratio described above to get the egg income for each phase. Feed costs were calculated by multiplying the cost of each diet (based on the local price of feed ingredients, from August 2009 to August 2010) by the total amount of feed consumed in a 2 wk period on a per hen basis. The feed costs per 907 kg for treatments 85 to 105% for phase 1 were 279.80, 307.00, $341.20, $376.48, and $410.10, respectively. Feed costs per 907 kg for treatments 85 to 105% for phase 2 were $248.20, $266.60, $295.10, $326.90, and $359.70, respectively. Feed costs per 907 kg for treatments 90 to 105% for phase 3 were $256.68, $266.20, $296.12, and $327.48, respectively. The 85% treatment was not fed during phase 3 due to the hens being removed from the treatment and switched to the 100% treatment (control) at 32 wk age. Return over feed cost was calculated by subtracting feed costs from egg income and expressing this figure (dollars/hen) in each laying phase.

Statistical Analysis

The experimental design was a randomized complete block design with location within house and initial body weight (BW) as blocking criteria. Data were analyzed by ANOVA using the GLM procedure of (SAS Institute (2010)), with dietary treatment and block as independent variables (Steel and Torrie, 1980). Treatment effects were evaluated using linear and quadratic orthogonal polynomial contrasts (Steel and Torrie, 1980). Treatment differences were considered significant at $P < 0.05$. Data for mortality were transformed using

Table 3. Composition of the experimental diets fed during phase 3 of the laying period[1].

Ingredient	Nutrient density (%)[2,3] Ninety percent treatment	Ninety-five percent treatment	One hundred percent treatment	One hundred five percent treatment
Corn	57.43	59.96	55.55	53.15
Soybean meal (48% CP)	17.24	20.04	22.34	25.13
Wheat middlings	5.00	—	—	—
Pork meal (50% CP)	5.00	5.00	5.00	5.00
Corn DDGS[4]	5.08	3.41	2.91	—
Soybean oil	—	0.70	2.64	4.43
Calcium carbonate[5]	8.93	9.33	9.78	10.27
Dicalcium phosphate	0.53	0.71	0.88	1.05
NaCl	0.25	0.28	0.31	0.35
Vitamin mix[6]	0.20	0.20	0.20	0.20
Mineral mix[7]	0.15	0.15	0.15	0.15
DL-Methionine	0.14	0.16	0.18	0.23
Larvadex	0.05	0.05	0.05	0.05
Calculated composition				
CP (%)	16.94	17.28	17.90	18.31
AME_n (kcal/kg)	2,757	2,824	2,890	2,957
Crude fat (%)	3.34	3.29	5.52	6.92
Calcium (%)	4.02	4.21	4.42	4.65
Phosphorus, nonphytate (%)	0.46	0.48	0.51	0.53
Sodium (%)	0.17	0.18	0.19	0.20
Digestible lysine (%)	0.74	0.78	0.83	0.87
Digestible methionine (%)	0.38	0.40	0.43	0.47
Digestible methionine + cysteine (%)	0.60	0.63	0.66	0.70
Analyzed composition (%)				
CP	17.40	18.02	17.68	18.52
Crude fat	3.50	2.95	3.00	5.80
Calcium	5.35	3.83	4.12	5.39
Total phosphorus	0.67	0.68	0.74	0.73
Sodium	0.19	0.14	0.18	0.19
Dry matter	89.40	89.00	89.00	89.80

[1]Phase 3 treatment diets were fed from 33 to 70 wk age (38 wk). Treatment 1 diet (85%) is not shown because hens on this treatment were switched to treatment 4 at 32 wk age.

[2]Percentage of recommended nutrient density.

[3]The feed costs per ton for treatments 90 to 105% were \$256.68, \$266.20, \$296.12, and \$327.48, respectively.

[4]DDGS = Distiller's dried grains with solubles.

[5]65% of calcium carbonate was supplied in particle sizes over 0.14 mm.

[6]Provided per kilogram of diet: vitamin A from vitamin A acetate, 4,400 IU; cholecalciferol, 1,000 IU; vitamin E from α-tocopheryl acetate, 11 IU; vitamin B_{12} 0.011 mg; riboflavin, 4.4 mg; d-pantothenic acid, 10 mg; niacin, 22 mg; menadione sodium bisulfate complex, 2.33 mg.

[7]Provided per kilogram of diet: manganese, 75 mg from manganese oxide; iron, 75 mg from iron sulfate; zinc, 75 mg from zinc oxide; copper, 5 mg from copper sulfate; iodine, 0.76 mg from ethylene diamine dihydroiodide; selenium, 0.1 mg from sodium selenite.

square-root transformation prior to analysis to ensure normality.

RESULTS

There were no significant differences in mortality due to the dietary treatments. The average mortality over the length of the trial for all replicates was 1.35%.

At 32 wk age, hens fed the 85% treatment experienced a decrease in egg production, with an average hen-day egg production of 65%, following a severe loss in body weight (BW) from 26 wk. At 32 wk age, hen-day egg production for hens on the 85% treatment was below 50% (Figure 1). At this time, hens fed the 85% treatment were switched to the 100% treatment (control) due to low egg production. The reasons for the dramatic drop in egg production by hens fed the 85% treatment was due to a feed mixing error that occurred 21 d after the start of feeding all phase 2 diets. It was discovered that salt was not added to treatment 85% at this time and the analyzed Na concentration was 0.04%. Thus, hens on this treatment were fed this diet for the remaining days of phase 2 diet feeding (21 d). After being switched to the control treatment, hens previously fed the 85% treatment had an average hen-day egg production of 68% at 33 wk age. After 2 wk, at 34 wk age, the hens had recovered and caught up with hens fed the other experimental treatments, having an average hen-day egg production of 92%. Production data for the 85% treatment were not statistically analyzed for data from 27 to 32, 33 to 70, and 19 to 70 wk age (Table 4).

A significant linear response to increasing nutrient density was observed for hen-day egg production from 33 to 70 and 19 to 70 wk age (Table 4). The 100% treatment had the highest production followed by the 95, 105, and 90% treatments during the 27 to 32 wk period. In addition, egg production was the greatest for

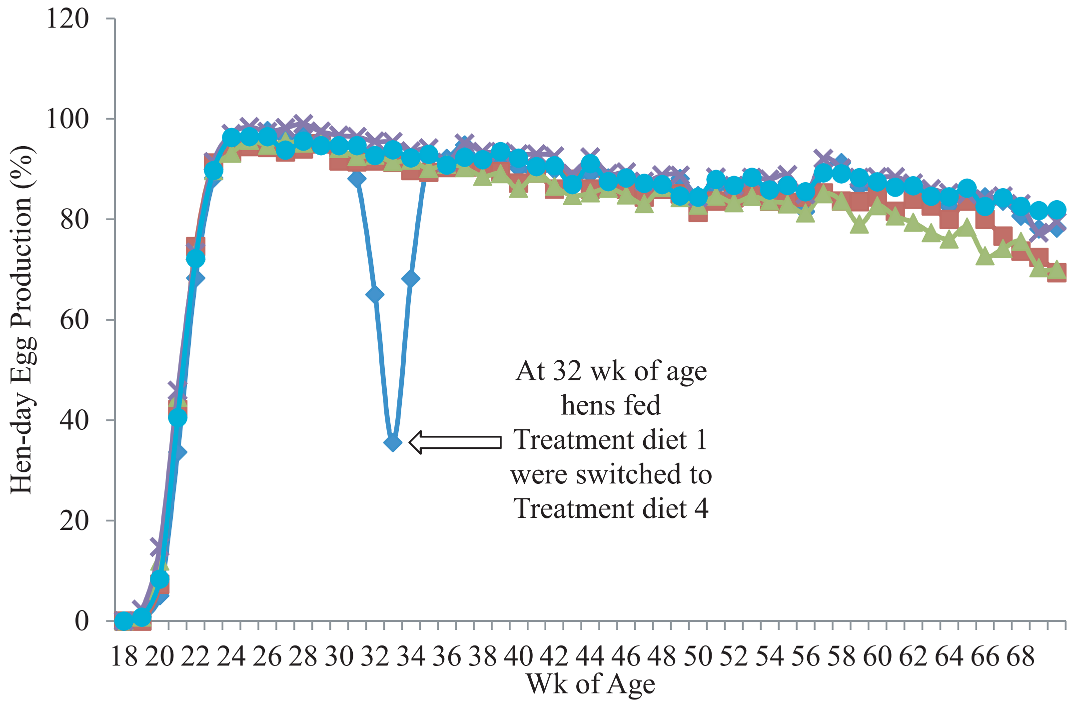

Figure 1. Weekly hen-day egg production of hens fed diets varying in nutrient density. Treatments were as follows: 1) 85% (◆), 2) 90% (■), 3) 95% (▲), 4) 100% (✕), and 5) 105% (●) of nutrient density of the control diet (100%), respectively. At 32 wk age, hens fed the 85% treatment were switched to the 100% treatment 4 (control). Phases 1 to 3 treatment diets were fed from 19 to 26 (8 wk), 27 to 32 (6 wk), and 33 to 70 (38 wk) wk age, respectively. Color version available online.

the 100% control treatment for the 33 to 70 and 19 to 70 wk periods.

There was a significant linear increase in egg weight by 1 to 2 g/egg from 19 to 26, 27 to 32, 33 to 70, and 19 to 70 wk age (Table 4). From the 19 to 26 wk period, the 85% treatment produced the lightest eggs. These data showed that the lightest eggs were produced from the 90% treatment and the heaviest eggs were produced from the 105% treatment during the 33 to 70 wk period and overall (19 to 70 wk age) period, respectively.

There was a significant linear increase in egg mass (grams egg per hen per day) in response to increasing nutrient density for all phases and 19 to 70 wk age (Table 4). In general, egg mass was highest for hens fed the 105% treatment and decreased linearly during all periods with the 85% treatment, producing the least egg mass during the 19 to 26 wk period.

An increase in dietary nutrient density resulted in a significant linear response in feed intake for hens during phase 1 (Table 5). Hens fed the 85% treatment consumed the most feed from 19 to 26 wk age, and the 90% treatment consumed the most feed from 27 to 32 wk age (Table 5). Birds adjusting feed intake to nutrient density was not supported by the data throughout the majority of the trial and lay cycle (33 to 70 wk age), while birds had small responses early in lay.

Table 5 shows that an increase in nutrient density resulted in a significant linear response in improved feed efficiency (grams egg per grams feed) for the 19 to 26, 27 to 32, 33 to 70, and 19 to 70 wk age periods. The 105% treatment had the best feed efficiency across 19 to 26, 27 to 32, 33 to 70, and 19 to 70 wk age, with a peak from 27 to 32 wk age of 0.57 (grams egg per grams feed).

Body weight of hens increased significantly with an increase in nutrient density (Table 5). Significant linear responses to an increase in nutrient density were seen at 27, 33, and 70 wk age. When BW was recorded at 33 wk age before the no-salt diet was fed, hens fed the 85% treatment had decreased to 1,241 g/hen. Since the hens fed the 85% treatment had consumed the no-salt diet for the remaining 21 d of phase 2, this contributed to the decline in their BW. When hens were weighed at 27, 33, and 70 wk age, those fed the 105% treatment were the heaviest.

Using the feed intake data from Table 5 and the calculated energy composition from Tables 1 to 3, the daily energy and selected nutrient intakes were computed (Table 6). These data showed that increasing the dietary energy density resulted in a significant linear response in daily energy and nutrient intakes (Table 6). This occurred in all phases. In addition, a significant quadratic response occurred for digestible Lys, Met, and Met and Cys from 19 to 26, 27 to 32, and 33 to 70 wk age, respectively. In phase 1, the calculated intakes of most of the nutrients were below the recommended amounts for the 85, 90, and 95% treatments, and met or exceeded the recommendation in the 100% and 105% treatments. In phases 2 and 3, the calculated Ca intakes were substantially below the recommended amounts in the 90 and 95% treatments, and adequate in the 100 and 105% treatments. In addition, calculated

Table 4. Effect of dietary energy and nutrient density on egg production, egg weight, and egg mass[1].

Treatment[2]	19 to 26 wk	27 to 32 wk[3]	33 to 70 wk[3]	19 to 70 wk[3]
	Hen-day egg production (%)			
85%	60.6	—	—	—
90%	62.2	92.9	84.3	81.9
95%	63.0	94.4	83.1	81.3
100%	65.0	97.4	88.6	86.0
105%	62.6	94.3	87.7	84.6
Pooled SEM	1.3	1.3	1.1	1.0
P-value				
Linear	0.11	0.24	0.01	0.01
Quadratic	0.17	0.12	0.89	0.71
	Egg weight (g/egg)			
85%	50.4	—	—	—
90%	50.9	55.9	60.4	58.4
95%	51.0	56.2	61.3	59.2
100%	51.6	56.8	61.0	59.1
105%	51.3	57.2	62.2	60.0
Pooled SEM	0.3	0.3	0.4	0.3
P-value				
Linear	0.02	0.01	0.01	0.01
Quadratic	0.37	0.76	0.80	0.89
	Egg mass (grams egg per hen per day)			
85%	30.5	—	—	—
90%	31.6	51.9	50.9	47.8
95%	32.1	53.0	50.9	48.1
100%	33.6	55.1	54.1	50.8
105%	32.1	54.0	54.6	50.8
Pooled SEM	0.7	0.8	0.3	0.3
P-value				
Linear	0.03	0.04	0.0002	0.001
Quadratic	0.14	0.20	0.74	0.79

[1]Data are means of 6 groups of 16 hens each.

[2]Percentage of recommended nutrient density.

[3]Twenty-one days after the start of feeding phase 2 diets, hens fed the 85% treatment diet were fed this diet without added salt until the end of phase 2. At 32 wk age, hens fed the 85% treatment were switched to the 100% treatment (control). Therefore, data from hens on the 85% treatment were omitted from the analysis of 27 to 32, 33 to 70, and 19 to 70 wk age. Data from hens on the original 100% treatment were only included in the analysis of 33 to 70 and 19 to 70 wk age.

Na intakes were below the recommended amounts in the 90% treatment only.

Significant linear responses due to nutrient density were observed for shell color from 27 to 70 wk age (Table 7). Significant linear responses were seen for neither shell breaking strength, albumen height, yolk weight, nor Haugh units. Significant quadratic responses to increasing nutrient density were noted for albumen height for the 27 to 32 wk period, and for albumen height, shell color, and Haugh units for 33 to 70 and 27 to 70 wk age, respectively.

The effect of diets varying in nutrient density on percent yolk and egg solids is depicted in Table 8. There were no linear responses to increasing nutrient density for any solids measurement during any phase.

Significant linear responses due to increasing nutrient density were observed for income from 27 to 32, 33 to 70, and 19 to 70 wk age (Table 9). As nutrient density increased, so did egg income. Significant linear responses due to increasing nutrient density were seen for feed cost during all 4 phases. Quadratic responses were seen from 33 to 70 wk age and overall. For income minus feed cost, significant linear responses were seen for 19 to 26, 27 to 32, and 19 to 70 wk age. In general, as nutrient density increased, income and feed cost increased, while income minus feed costs decreased.

DISCUSSION

The objective of the present study was to determine the effects of feeding diets of 5 different energy and nutrient densities to Hy-Line W-36 hens, on measurements of long-term egg production performance and economic effects. In previous research, Harms et al. (2000), Wu et al. (2005, 2007), and Rao et al. (2014) all showed that hens would linearly adjust their feed intake in response to nutrient density increases or decreases. Using DeKalb White and Bovans White hens, Wu et al. (2005) showed that when dietary energy increased from 2,719 to 2,956 kcal of nitrogen-corrected apparent metabolizable energy (AME_n)/kg, hens adjusted their feed intake from 107.6 to 101.1 g/hen per day to achieve

Table 5. Effect of dietary energy and nutrient density on feed intake, feed efficiency, and body weight[1].

Treatment[2]	19 to 26 wk	27 to 32 wk[3]	33 to 70 wk[3]	19 to 70 wk[3]
	Feed intake (g/hen/day)			
85%	83.6	—	—	—
90%	83.4	97.6	103.9	100.1
95%	82.2	96.7	102.8	98.9
100%	83.5	97.4	103.8	99.9
105%	81.6	95.4	102.9	98.7
Pooled SEM	0.6	0.7	0.4	0.5
P-value				
Linear	0.04	0.09	0.28	0.16
Quadratic	0.71	0.44	0.77	0.98
	Feed efficiency (grams egg per grams feed)			
85%	0.39	—	—	—
90%	0.39	0.54	0.48	0.47
95%	0.40	0.56	0.49	0.48
100%	0.40	0.56	0.50	0.49
105%	0.40	0.57	0.50	0.50
Pooled SEM	0.003	0.005	0.004	0.004
P-value				
Linear	0.001	0.003	0.002	0.01
Quadratic	0.70	0.31	1.00	1.00
	Body weight (g/hen)			
	19 wk	27 wk	33 wk	70 wk[3]
85%	1,156	1,423	1,241	—
90%	1,157	1,426	1,489	1,637
95%	1,157	1,453	1,497	1,696
100%	1,157	1,492	1,562	1,743
105%	1,169	1,516	1,578	1,794
Pooled SEM	12.8	16.1	19.1	18.4
P-value				
Linear	0.53	0.001	0.001	0.001
Quadratic	0.67	0.38	0.84	0.82

[1]Data are means of 6 groups of 16 hens each.

[2]Percentage of recommended nutrient density.

[3]Twenty-one days after the start of feeding phase 2 diets, hens fed the 85% treatment diet were fed this diet without added salt until the end of phase 2. At 32 wk age, hens fed the 85% treatment were switched to the 100% treatment (control). Therefore, data from hens on the 85% treatment were omitted from the analysis of 27 to 32, 33 to 70, and 19 to 70 wk age. Data from hens on the original 100% treatment were only included in the analysis of 33 to 70 and 19 to 70 wk age.

a similar amount of dietary energy intake. In Harms et al. (2000), Hy-Line W-36 hens responded by eating significantly more feed that was low in energy and less feed that was high in energy. However, they also stated that the Hy-Line W-98 and Hy-Line Brown hens were more sensitive to the change in energy than the Hy-Line W-36 or DeKalb White hens. In Rao et al. (2014), Babcock BV300 hens ate more feed when fed a low-energy diet (2,399 kcal/kg) versus a high-energy diet containing 2,700 kcal/kg metabolizable energy. These changes in feed intake are not in agreement with the results of the current study although it would appear that the Hy-Line W-36 has become even less sensitive to dietary energy content since the study by Harms et al. (2000). In Harms et al. (2000), the energy content of the low-energy diet was 2,519 kcal/kg, while in the current study the 85% treatment had an energy content of 2,750 kcal/kg. Thus, the differences in energy concentrations in both studies may explain the varying results. Jalal et al. (2007) found that 22- to 50-week-old Hy-Line W-36, Hy-Line Brown, Babcock B300, and Shaver White hens did not respond to varying dietary energy level diets between 2,810 and 2,900 kcal/kg. Jalal et al. (2007) suggested that the metabolizable energy content of the low-energy diet may have been too high to induce a feed-intake adjustment. In the present study, significant linear responses in feed intake to increasing energy and nutrient density were only observed from 19 to 26 and 27 to 32 wk age, and only by a small amount (2 to 5 g/d), which was not enough to adjust to a constant energy intake. Hens altered their feed intake in response to energy and nutrient density only in the early stages of the lay cycle, perhaps adjusting to the nutrient balance of the feed. Overall, the W-36 hens did not alter feed intake throughout the majority of the experiment (33 to 70 wk age) as was hypothesized. Significant increasing linear effects due to increasing energy and nutrient density were observed for most parameters measured, including hen-day egg production, egg weight, egg mass, feed efficiency, energy intake, and body weight (BW).

Table 6. Calculated daily absolute intakes of energy and selected nutrients[1].

Item	Treatment[2] 85%	90%	95%	100%	105%	Pooled SEM	P-value Linear	Quadratic	Recommended[3]
Phase 1, 19 to 26 wk age (8 wk)									Lay to 32 wk age
AME_n (kcal/d)	230	235	237	246	246	1.66	0.0001	0.65	—
Ca (g/d)	3.54	3.69	3.82	4.07	4.19	0.03	0.0001	0.62	4.00
P, nonphytate (mg/d)[4]	443	459	477	509	522	3.41	0.0001	0.46	500
Na (mg/d)	159	167	173	184	188	1.23	0.0001	0.60	180
Digestible Lys (mg/d)	769	792	830	893	930	6.00	0.0001	0.03	805
Digestible Met (mg/d)	393	417	436	468	490	3.15	0.0001	0.42	394
Digestible Met + Cys (mg/d)	602	626	649	685	710	4.63	0.0001	0.38	676
Phase 2, 27 to 32 wk age (6 wk)									33 to 44 wk age
AME_n (kcal/d)	—	271	270	283	284	3.12	0.0019	0.84	—
Ca (g/d)	—	3.94	4.09	4.32	4.46	0.03	0.0001	0.90	4.20
P, nonphytate (mg/d)[4]	—	498	513	545	553	4.38	0.0001	0.27	480
Na (mg/d)	—	176	184	195	200	1.34	0.0001	0.36	180
Digestible Lys (mg/d)	—	839	870	935	973	6.43	0.0001	0.59	750
Digestible Met (mg/d)	—	429	464	497	515	3.39	0.0001	0.03	368
Digestible Met + Cys (mg/d)	—	664	696	731	754	5.05	0.0001	0.36	630
Phase 3, 33 to 70 wk age (38 wk)									45 to 58 wk age
AME_n (kcal/d)	—	286	290	300	304	1.28	0.0001	0.84	—
Ca (g/d)	—	4.18	4.33	4.59	4.78	0.02	0.0001	0.22	4.35
P, nonphytate (mg/d)[4]	—	478	493	529	545	2.18	0.0001	0.86	460
Na (mg/d)	—	177	185	197	206	0.82	0.0001	0.87	180
Digestible Lys (mg/d)	—	769	802	862	895	3.54	0.0001	0.87	710
Digestible Met (mg/d)	—	395	411	446	484	1.84	0.0001	0.0001	348
Digestible Met + Cys (mg/d)	—	623	648	685	720	2.85	0.0001	0.06	596

[1]Calculated using feed-intake data in Table 5 and diet composition in Tables 1 to 3.

[2]Percentage of recommended nutrient density.

[3]2009 Hy-Line Management guide recommendations.

[4]The Hy-Line recommendations are for available P.

Data for hen-day egg production showed that hens fed treatment diets 2 and 3 (90 and 95% of control) laid fewer eggs than those fed treatment diets 4 and 5 (100 and 105% of control).

Leeson et al. (2001) found that as long as nutrient balance is maintained in low-density diets, diets with an AME_n as low as 2,465 kcal/kg and crude protein (CP) as low as 15.2% can be adequate to support a full cycle of production. However, hens fed the 85% treatment were fed an AME_n content of 2,750 kcal/kg and CP content of 19.66% for phase one (19 to 26 wk age), as well as 2,700 kcal/kg AME_n and 18.63% CP in phase 2 (27 to 32 wk age). As was noted, hens fed the 85% treatment never reached the energy and protein limits established by Leeson et al. (2001). However, Leeson et al. (2001) did not use W-36 laying hens in his trial, so it is possible that the older-generation Shaver White hens could tolerate lower amounts of nutrients and continue to produce eggs at sufficient levels.

It was hypothesized that energy and certain nutrients, especially calcium and phosphorus, were neither supplied nor consumed in adequate amounts to support the egg production by hens fed the 85% treatment. In the early stages of the lay cycle, young hens have different nutrient requirements than older hens, and usually need higher nutrient concentrations due to low feed intake (NRC, 1994). It can be concluded that the 85% treatment offered neither enough nutrients nor energy for a young bird to be able to reach production in the first phase, and that the W-36 laying hen does not have the capacity to increase its feed intake when fed a diet of low nutrient-density. The error in feed mixing also contributed to this effect. This caused performance to suffer somewhat early in the lay cycle.

Egg production, egg weight, egg mass, feed efficiency, energy intake, and BW all increased in response to increased nutrient density. Leeson et al. (2001) saw similar results, when birds fed diets with the lowest nutrient density produced the fewest eggs. Leeson et al. (2001) also saw a trend in reduced egg size when diet nutrient density was reduced. However, their results showed small effects and were only significant at isolated measurements. Leeson et al. (2001) similarly reported that a decline in nutrient density showed a decline in feed efficiency. The statement by Leeson and Summers (2009) that high-energy diets can improve feed efficiency agrees with the results seen in the present study. In the present study, BW was also greatly affected by energy and nutrient density, with hens fed a higher-density diet being heavier. Initial BWs of laying hens were lower than normally expected in the W-36 laying hen possibly because the birds were floor-raised. However, the lower initial BW inhibited neither the age of onset of egg production, peak egg production, growth, nor overall production performance. Not many differences were seen in the quality or components of eggs in response to nutrient density. Therefore, the greatest benefits and effects of energy and nutrient density on the laying hen were the production of and size of the egg produced, as well as the feed efficiency of the hens.

Table 7. Effect of dietary energy and nutrient density on egg quality[1].

Age (wk)	Quality measure[3]	Treatment[2] 85%[4]	90%	95%	100%	105%	Pooled SEM	P-value Linear	Quadratic
27 to 32[5]	Breaking strength (kg)	—	4274	4371	4317	4291	66.2	0.99	0.37
	Egg weight (g)	—	55.1	55.4	55.7	56.0	0.3	0.05	0.99
	Albumen height (mm)	—	8.0	7.7	7.9	8.1	0.1	0.24	0.001
	Shell color	—	9.7	10.0	10.0	9.1	0.3	0.22	0.07
	Yolk weight (g)	—	14.0	14.2	14.1	14.0	0.1	0.72	0.09
	Haugh units (dimensionless)	—	90.7	88.7	89.6	90.6	0.3	0.64	0.0003
33 to 70[6]	Breaking strength (kg)	—	3890	3742	3769	3826	76.9	0.64	0.20
	Egg weight (g)	—	60.0	60.6	60.6	61.9	0.5	0.01	0.47
	Albumen height (mm)	—	7.3	7.0	7.1	7.2	0.1	0.51	0.03
	Shell color	—	9.0	9.0	9.1	8.4	0.2	0.07	0.04
	Yolk weight (g)	—	16.9	17.4	17.2	17.4	0.2	0.14	0.35
	Haugh units (dimensionless)	—	84.8	82.9	83.3	83.4	0.5	0.07	0.05
27 to 70[7]	Breaking strength (kg)	—	3976	3896	3886	3992	73.5	0.61	0.44
	Egg weight (g)	—	59.0	59.4	59.6	60.7	0.4	0.01	0.42
	Albumen height (mm)	—	7.4	7.2	7.3	7.4	0.1	0.65	0.01
	Shell color	—	9.1	9.2	9.297	8.6	0.2	0.05	0.02
	Yolk weight (g)	—	16.3	16.6	16.5	16.6	0.1	0.17	0.45
	Haugh units (dimensionless)	—	86.0	84.2	84.5	84.8	0.4	0.10	0.03

[1]Data are means of 6 groups of 16 hens each. A maximum of 30 eggs for each group were measured for egg quality.

[4]Percentage of recommended nutrient density.

[3]Measurements taken once every 4 wk. No measurements were taken from 19 to 26 wk age.

[4]Twenty-one days after the start of feeding phase 2 diets, hens fed the 85% treatment diet were fed this diet without added salt until the end of phase 2. At 32 wk age, hens fed the 85% treatment were switched to the 100% treatment (control). Therefore, data from hens on the 85% treatment were omitted from the analysis of 27 to 32, 33 to 70, and 27 to 70 wk age. Data from hens on the original 100% treatment were only included in the analysis of 33 to 70 and 27 to 70 wk age.

[5]Values are averages of 2 sampling periods taken at 26 and 30 wk age.

[6]Values are averages of 9 sampling periods taken at 34, 38, 42, 46, 50, 59, 62, 66, and 70 wk age.

[7]Values are the average of all sampling periods at 27, 30, 34, 38, 42, 46, 50, 59, 62, 66, and 70 wk age.

Table 8. Effect of dietary energy and nutrient density on percent yolk and egg solids[1].

Age (wk)	Quality measure (%)[3]	Treatment[2] 85%[4]	90%	95%	100%	105%	Pooled SEM	P-value Linear	Quadratic
27 to 32[5]	Yolk	—	28.6	29.2	29.0	28.7	0.4	0.97	0.23
	Yolk solids	—	49.8	50.0	49.9	49.3	0.2	0.11	0.06
	White solids	—	12.5	12.5	12.6	12.7	0.1	0.26	0.79
	Whole solids	—	23.2	23.5	23.4	23.2	0.2	0.96	0.18
33 to 70[6]	Yolk	—	32.1	32.4	31.9	31.8	0.3	0.20	0.44
	Yolk solids	—	50.4	50.4	50.3	50.6	0.1	0.36	0.25
	White solid	—	13.7	13.6	13.7	12.8	0.5	0.25	0.47
	Whole solids	—	25.5	25.5	25.3	24.8	0.4	0.18	0.46
27 to 70[7]	Yolk	—	31.5	31.9	31.4	31.2	0.3	0.27	0.35
	Yolk solids	—	50.3	50.3	50.2	50.4	0.1	0.64	0.55
	White solids	—	13.5	13.4	13.5	12.8	0.4	0.26	0.48
	Whole solids	—	25.1	25.2	25.0	24.5	0.3	0.20	0.41

[1]Data are means of 6 groups of 16 hens each. Egg solids were analyzed for 7 eggs for each group.

[2]Percentage of recommended nutrient density.

[3]Measurements taken once every other month. No measurements were taken from 19 to 26 wk age.

[4]Twenty-one days after the start of feeding phase 2 diets, hens fed the 85% treatment diet were fed this diet without added salt until the end of phase 2. At 32 wk f age, hens fed the 85% treatment were switched to the 100% treatment (control). Therefore, data from hens on the 85% treatment were omitted from the analysis of 27 to 32, 33 to 70, and 27 to 70 wk age. Data from hens on the original 100% treatment were only included in the analysis of 33 to 70 and 27 to 70 wk age.

[5]Values are an average of one sampling period taken at 31 wk age.

[6]Values are averages of 5 sampling periods taken at 38, 46, 54, 62, and 69 wk age.

[7]Values are the average of all sampling periods at 31, 38, 46, 54, 62, and 69 wk age.

Compared to three other strains of hens (Delta, H&N, and Hy-Line W-77), the Hy-Line W-36 had the highest percentage of whole egg solids and the percentage of egg solids was hardly influenced by egg size, except for when eggs reached jumbo size (Ahn et al., 1997). Whole egg, white, and yolk solids values for the Hy-Line W-36 were 24.52, 11.99, and 50.89%, respectively. These values for whole egg, white, and yolk solids found by Ahn et al. (1997) are fairly consistent with values found in this study (Table 8).

Table 9. Effect of dietary energy and nutrient density on egg economics[1].

Treatment[2]	Economics ($/hen)			
	19 to 26 wk	27 to 32 wk[3]	33 to 70 wk[3]	19 to 70 wk[3]
	Income[4]			
85%	1.88	—	—	—
90%	1.97	2.92	23.16	28.05
95%	1.97	2.99	23.08	28.04
100%	2.04	3.12	24.49	29.65
105%	2.00	3.08	24.47	29.56
Pooled SEM	0.05	0.06	0.27	0.32
P-value				
Linear	0.06	0.03	0.01	0.01
Quadratic	0.32	0.35	0.90	0.90
	Feed cost[5]			
85%	1.13	—	—	—
90%	1.24	1.20	7.82	10.26
95%	1.36	1.32	8.01	10.69
100%	1.51	1.47	9.00	11.99
105%	1.60	1.59	9.87	13.06
Pooled SEM	0.01	0.01	0.04	0.05
P-value				
Linear	0.001	0.0001	0.001	0.001
Quadratic	0.87	1.00	0.001	0.001
	Income minus feed cost[6]			
85%	0.75	—	—	—
90%	0.73	1.72	15.34	17.79
95%	0.61	1.67	15.07	17.35
100%	0.53	1.65	15.49	17.66
105%	0.40	1.49	14.60	16.50
Pooled SEM	0.05	0.06	0.27	0.32
P-value				
Linear	0.001	0.02	0.16	0.03
Quadratic	0.29	0.34	0.29	0.28

[1]Data are means of 6 groups of 16 hens each.

[2]Percentage of recommended nutrient density.

[3]Twenty-one days after the start of feeding phase 2 diets, hens fed the 85% treatment diet were fed this diet without added salt until the end of phase 2. At 32 wk age, hens fed the 85% treatment were switched to the 100% treatment (control). Therefore, data from hens on the 85% treatment were omitted from the analysis of 27 to 32, 33 to 70, and 19 to 70 wk age. Data from hens on the original 100% treatment were only included in the analysis of 33 to 70 and 19 to 70 wk age.

[4]Egg income was calculated every 2 wk. The ratio of the total eggs laid in 2 wk over total eggs laid over 2 d (consecutive) was used to estimate the number of eggs laid in each size category. Urner-Barry egg prices at 20, 27 and 34 wk age were used to calculate egg income for each phase. These egg prices were: $1.06, $0.99, $0.96, $0.76, and $0.64 for phase 1; $1.06, $1.02, $0.99, $0.87, and $0.68 for phase 2; and $1.30, $1.34, $1.34, $1.10, and $0.88 for phase 3 (regarding jumbo, extra-large, large, medium, and small eggs, respectively). The percent of jumbo, extra-large, large, medium, and small eggs laid over 2 d were multiplied by their respective Urner-Barry Midwest 5 day average price quote, added together, and multiplied by the ratio described above to get the egg income for each phase. The percent of jumbo, extra-large, large, medium, and small eggs laid over 2 d were multiplied by their respective Urner-Barry Midwest 5 day average price quote, added together, and multiplied by the ratio described above.

[5]Feed costs were calculated by multiplying the cost of each diet (based on the local price of feed ingredients in each diet) by the total amount of feed consumed in 2 wk/hen. The feed costs per 907 kg for treatments 85 to 105% for phase 1 were $279.80, $307.00, $341.20, $376.48, and $410.10, respectively. Feed costs per 907 kg for treatments 85 to 105% for phase 2 were $248.20, $266.60, $295.10, $326.90, and $359.70, respectively. Feed costs per 907 kg for treatments 85 to 105% for phase 3 were $256.68, $266.20, $296.12, and $327.48, respectively. The 85% treatment was not fed during phase 3 due to the hens being removed from the treatment and switched to the 100% treatment (control) at 32 wk age.

[6]Income minus feed costs was calculated by subtracting feed cost from egg income.

Egg income increased linearly with increasing energy and nutrient density, but appeared to level off between the 100 and 105% treatment. As expected, feed cost also increased linearly with increasing energy and nutrient density, but the higher feed cost of the 105% treatment did not result in numerically greater egg income, so the return over feed cost was not favorable for the 105% treatment. The income minus feed cost (dollars/hen per laying phase) was lowest for hens fed the 105% treatment and there was a numerically small, but significant linear decrease in income minus feed cost due to increasing nutrient density from 19 to 70 wk age. These results indicate that, even though hens fed higher-energy and nutrient dense diets had improved feed efficiency and produced more eggs of larger sizes, the income from these did not offset the higher costs of the high energy and density diets.

In summary, increasing energy and nutrient density in the diet of Hy-Line W-36 laying hens increased egg production, egg weight, egg mass, feed efficiency, energy intake, BW, income, and feed cost, as well as decreased income minus feed cost. Furthermore, many of these benefits did not take effect during early production and seem to be most effective in later stages of the lay cycle, perhaps readying the birds for better egg-production persistency with age. Furthermore, in this study, hens were not able to adjust their feed intakes and the lowest energy density diet produced reduced egg production performance.

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