Effects of a premolt calcium and low-energy molt program on laying hen performance, egg quality, and economics[1]

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ABSTRACT The objectives of this study were to evaluate and compare the effects of production, physiology, egg quality, and economics of laying hens housed in a cage system when offered a calcium premolt treatment and low-energy molt diets versus a traditional feed withdrawal (FW) treatment during and after molt. In total, 981 Hy-Line W-36 laying hens (85 wk of age) housed 3 per cage were used. Six treatments were compared in a 2 × 3 factorial design with 2 calcium premolt treatments (fine and coarse) and 3 molt diets (FW, soybean hulls, and wheat middlings). The coarse Ca was a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$, whereas the fine Ca was an all-fine $CaCO_3$. Both diets were formulated to contain 4.6% Ca, such that only the particle size of the $CaCO_3$ differed. Production parameters in experiment 1 included egg production, egg weight and mass, specific gravity, Haugh units, egg components, feed consumption and utilization, and BW. Physiological parameters in experiment 2 included ovary and oviduct weights, femur- and humerus-ash percentages, heterophil to lymphocyte ratios, plasma Ca and inorganic P concentrations, and alkaline phosphatase activity. Data were analyzed by ANOVA and $P < 0.05$ was significant. The fine-Ca premolt treatment was more effective than the coarse-Ca treatment at decreasing egg production during molt and increasing it postmolt, regardless of the molt diet. The FW molt diet resulted in the greatest decrease in production, but the soybean hulls diet resulted in lower production and ovary and oviduct weights during molt compared with those of the wheat middlings molt diet. Therefore, a fine-Ca premolt treatment and a low-energy molt diet, particularly soybean hulls, can be useful alternatives to a FW molt.

Key words: economics, laying hen, molt, performance, physiology

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INTRODUCTION

In the egg-laying industry, hens may be exposed to an induced molt to extend their productive life, which allows for a second more productive egg-laying cycle. During molt, the reproductive tract regresses. Once molt is complete, egg production increases and eggshell quality improves postmolt compared with premolt (Webster, 2003). In the United States, molt programs are typically induced for laying hens between 65 and 75 wk of age based on economics. Traditionally, molt has been induced by feed withdrawal (**FW**) ranging from 4 to 14 d, accompanied by light restriction or total removal of water for up to 3 d (Cunningham and Mauldin, 1996; Berry, 2003). Contrary to feeding a low-energy molt feed during molt, the FW molt procedure ensures a complete cessation of egg production and better postmolt egg-production performance Biggs et al. (2003, 2004). Nevertheless, the FW molt procedure has raised societal concerns about its possible effects on the overall well-being of the laying hen (Holt, 1992; Webster, 2003; McCowan et al., 2006). In the United States, industry groups have recommended that after January 1, 2006, producers implement only nonfasting molt programs that have been defined as having available water and a feed source suitable for nonproducing hens (American Veterinary Medical Association, 2005; United Egg Producers, 2008), and some fast-food chains specify that their companies will no longer purchase eggs that are produced from a laying operation that uses an FW molting program (Anonymous, 2000).

Several studies have compared the effectiveness of feeding low-energy feeds, such as wheat middlings (**WM**) or soybean hulls (**SH**) as an alternative to FW for inducing molt (Biggs et al., 2003, 2004; Koelkebeck et al., 2006). Although FW resulted in a more complete and better postmolt performance, Biggs et al. (2003, 2004), Koelkebeck et al. (2006), and Mejia et al. (2010) concluded that the low-energy feeds were suitable alternatives for inducing a molt with regard to better post-

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molt performance. An additional consideration is that feeding a Ca-deficient diet can inhibit ovulation and induce molt (Douglas et al., 1972; Hurwitz et al., 1975). These Ca-deficient diets contained approximately 0.3% Ca, whereas the recommended content is approximately 4.6% Ca. The particle size of Ca is also important for egg production and shell formation, with coarse Ca solubilized more slowly from the digestive tract compared with fine Ca (Scott et al., 1971; Zhang and Coon, 1997). Because of the lower solubility, the coarse Ca is retained longer in the crop than fine Ca, and the coarse Ca is therefore present in the intestines at night, when hens do not consume feed, and the rate of shell formation is the greatest. Therefore, it may be possible that a fine-Ca premolt treatment will not allow the hen access to sufficient Ca to meet the needs for eggshell formation and the production of the luteinizing-hormone surge that is needed for ovulation (Luck and Scanes, 1979, 1980; Johnson, 2000). This Ca premolt treatment has been previously examined in regards to laying-hen behavior and heterophil to lymphocyte ratios by Dickey et al. (2010). The authors concluded that a Ca premolt treatment did not affect the behavior of the laying hen. The low-energy molt diets did not adversely affect behavior compared with FW and did not increase the heterophil to lymphocyte ratio; therefore, the low-energy molt diets, in combination with a Ca premolt treatment, could be useful alternatives for inducing molt in laying hens with the same efficacy as the FW molt. However, effects of Ca premolt on production, physiology, egg quality, and economics of laying hens housed in a cage system are unknown. Therefore, the objectives of this study were to evaluate the effects of production, physiology, egg quality, and economics of laying hens housed in a cage system when offered a Ca premolt treatment and low-energy molt diets versus a traditional FW treatment during and after molt.

MATERIALS AND METHODS

Housing and Husbandry

The project was approved by the Iowa State University Institutional Animal Care and Use Committee. The research was conducted over a 29-wk period (July 2007–February 2008) at the Iowa State University Poultry Research Center in Ames. In total, 981 Hy-Line W-36 laying hens (85 wk of age) weighing 1.7 ± 0.2 kg were used in 2 experiments. Hens were obtained from a single source and were considered to have a healthy reproductive status. Hen beaks were trimmed before 2 wk of age, according to recommendations from the Hy-Line W-36 commercial management guide (Hy-Line International, West Des Moines, IA). All cages were located in 2 identical light-controlled, mechanically ventilated rooms. Hens were housed 3 per cage (30.5-cm wide × 40.6-cm deep × 44.5-cm high) providing 413 cm^2/hen. Wire flooring was used in all cages (Chore-Time, Milford, IN) and each cage was equipped with a plastic self-feeder and a nipple drinker. In room 1, the feeders were 29.2 cm in length, whereas the feeders were 20.3 cm in length in room 2. Hens were able to see neighboring feed troughs but were unable to reach them because of vertical plastic barriers between troughs.

Experiments 1 and 2 were conducted simultaneously to evaluate effects of a Ca premolt treatment followed by low-energy molt diets or FW. Experiment 1 examined production parameters, including feed consumption, feed utilization, BW, egg production, egg weight, egg mass, specific gravity, Haugh units, egg components, mortality, and economics. Experiment 2 examined physiological parameters, including plasma Ca and inorganic P concentrations, alkaline phosphatase (**ALP**) activity, ovary and oviduct weight, and bone-ash percentage.

Treatments and Experimental Design

In experiment 1, 264 cages were used, and 63 cages were used for experiment 2. Hens were weighed and assigned to cages (n = 3 hens/cage) so that the mean cage BW was similar across treatments. The experimental design for both experiments was a randomized complete block design with treatments in a 2 × 3 factorial arrangement with 2 Ca premolt treatments and 3 low-energy molt diets (Figure 1). Experiment 1 had a total of 44 blocks; within each block there were 6 individual laying-hen cages representing the 6 dietary treatment combinations. The experimental unit was the cage containing 3 hens (n = 264) for production, egg quality, and economic measures. Experiment 2 had 6 hens representing the baseline period and then 10 blocks; within each block there were 6 individual laying-hen cages representing the 6 dietary treatment combinations. The experimental unit was the individual hen (n = 189) for the physiological measures.

Baseline Period. Hens were exposed to a 16-h light photoperiod. Hens were 85 wk of age at the beginning of the 2-wk baseline period, which was defined as the period before any experimental diets were applied. The hens had free access to water and a laying-hen diet formulated to meet or exceed recommendations from the Hy-Line W-36 commercial management guide (Table 1).

Ca Premolt Treatment. Hens were exposed to a 24-h light photoperiod for a 1-wk period (87–88 wk of age; Anderson and Havenstein, 2007). After the baseline period, hens (87 wk of age) received a diet in which the main Ca source was either a combination (50:50) of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or all-fine $CaCO_3$ (Table 1). Both diets contained 4.61% Ca, such that only the particle size of the Ca supplement differed between the 2 treatments (which both supplied the recommended amounts of calcium). These diets were fed for 1 wk and the hens had free access to water.

During Molt. Hens were exposed to an 8L:16D photoperiod for the first 3 wk and then light was increased

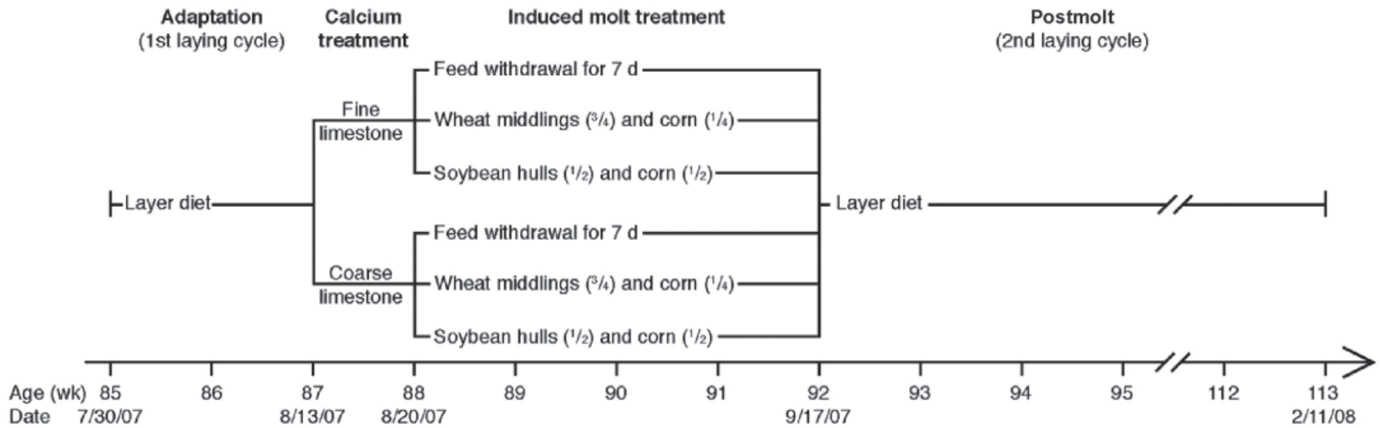

Figure 1. An outline of the 2 calcium premolt treatments and the 3 low-energy molt diets.

to 12 h at the beginning of the last week of molt. The 3 low-energy molt diets (FW, SH, or WM) were fed for a total of 28 d (from 88–92 wk of age). Hens fed the FW molt diet (Table 1) were restricted from feed consumption for 7 d with free access to water, followed by 21 d of skip-a-day feeding restricted to 60 g of feed per feeding day per hen. This feeding regimen allowed hens assigned to the FW group to engage in feeding-related behaviors during molt. The hens fed the WM and SH low-energy molt diets (Table 1) were provided free access to feed and water during the entire 28-d molt period. Vitamins and minerals were added to the WM and SH molt diets to make the diets acceptable for nonproducing hens according to recommendations from the Hy-Line W-36 commercial management guide. Ground corn grain was added to the molt diets to improve flowability (75:25, WM:corn; and 50:50, SH:corn; Koelkebeck et al., 2006).

Postmolt. Hens were exposed to an incremental 1-h increase in light each week until a 16-h photoperiod was reached. After the 4 wk of molt diets, all hens were fed a commercial-type laying hen diet for egg-producing hens (Table 1) for 22 wk (from 92–114 wk of age). This period was divided into the first 2 wk postmolt and the next 20 wk according to diet recommendations from the Hy-Line W-36 commercial management guide. Hens were given free access to water.

Data Collection

Experiment 1. In total, 792 hens were used to measure production parameters. Feed consumption and BW were recorded weekly until 4 wk postmolt (hens at 95 wk of age) and were then recorded once every 3 wk. During molt, feed consumption and BW of hens assigned to the FW treatment were recorded every other day during the skip-a-day feeding. Feed consumption was calculated as grams of feed disappearance divided by the number of hens per cage. Feed utilization was calculated as grams of egg mass divided by grams of feed consumed.

Egg production was recorded daily and eggs collected over a 24-h period each week throughout the experiment were saved for weight determination. Egg mass was calculated as egg production × egg weight. During the 4-wk-long molt period, egg weight and egg mass were determined during the fourth week only because of low egg production.

Egg specific gravity was determined using eggs collected over a 24-h period twice before molt (hens at 86

Table 1. Experimental diets used for laying hens[1]

Period	AME_n, kcal/kg	CP, %	Ca, %	Nonphytate P, %	Na, %	Lys, %	Met + cys, %
Baseline	2,776	16.07	4.61	0.40	0.18	0.91	0.66
Calcium premolt[2]							
Fine Ca	2,776	16.07	4.61	0.40	0.18	0.91	0.66
Coarse Ca	2,776	16.07	4.61	0.40	0.18	0.91	0.66
During molt							
Feed withdrawal[3]	2,817	15.27	2.00	0.25	0.11	0.80	0.91
Wheat middlings	2,198	13.09	2.00	0.25	0.14	0.57	0.33
Soybean hulls	2,216	8.88	2.00	0.25	0.10	0.44	0.30
After molt							
First 2 wk	2,910	16.50	3.85	0.50	0.17	0.94	0.62
Last 20 wk	2,880	16.05	4.10	0.44	0.19	0.91	0.62

[1]Calculated values. Diets contained corn, soybean meal, vitamins, trace minerals, dicalcium phosphate, and calcium carbonate.

[2]Calcium was supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or as an all-fine $CaCO_3$ mixed into a laying-hen diet for a 1-wk premolt Ca treatment.

[3]The 7-d feed withdrawal was followed by restricted skip-a-day feeding (60 g/hen).

and 87 wk of age) and 8 times after molt (hens at 96 to 99, 102, 105, 108, and 111 wk of age) by the method described by Bregendahl et al. (2008). Eggs collected from a second 24-h period, once before molt (hens at 86 wk of age) and once after molt (hens at 104 wk of age), were used for determination of Haugh units by the method described by Bregendahl et al. (2008). Egg components, defined as dry yolk percentage, dry albumen percentage, and dry shell percentage, of eggs collected over a 24-h period before molt (hens at 86 and 87 wk of age) and after molt (hens at 96 to 99, 108, and 113 wk of age) were determined by following the method of Bregendahl et al. (2008). Mortality was recorded daily throughout the experiment.

The economics were evaluated as the return over feed cost, calculated from the cost of feeding the hens and the price obtained from the eggs. The feed cost was determined from the feed composition, feed consumption, and cost of feed ingredients obtained from the October 13, 2008 edition of Feedstuffs magazine (Chicago market). Because the mean egg weight of all eggs from the treatments corresponded to large eggs (56–63 g), the egg value was calculated by multiplying the total egg count by the value of large eggs listed by the October 13, 2008 edition of Feedstuffs magazine (Chicago market).

Experiment 2. Blood was collected from 189 laying hens at the end of the baseline period (9 hens; 86 wk of age), at the end of the Ca premolt treatment (9 hens from each of the 2 Ca treatments; 87 wk of age), during the middle and end of the molt period (9 hens from each of the 6 treatments; 89 and 91 wk of age), and at the end of the postmolt period (9 hens from each of the 6 treatments; 113 wk of age). Blood was collected from the brachial vein into heparinized 15-mL centrifuge tubes. The tubes were stored on ice until analysis.

Blood was centrifuged (2,000 × g for 20 min at 4°C) and the plasma was collected and stored at −80°C until analysis for concentrations of plasma Ca and inorganic P and for ALP activity. The plasma Ca concentrations were determined using a digital flame analyzer at the Iowa State University College of Veterinary Medicine Pathology Laboratory. The inorganic P concentrations were determined after deproteinization with 12.5% trichloroacetic acid by the method of Gomori (1942), modified for use with a microplate spectrophotometer. The ALP activity in the plasma was assayed according to the manufacturer's instruction using a QuantiChrom kit (BioAssay Systems, Hayward, CA) with a microplate spectrophotometer.

After blood was collected, all hens were killed by CO_2 asphyxiation (American Veterinary Medical Association, 2007). Fresh weights of ovaries and oviducts were collected to determine the degree of ovarian regression. Eggs in the reproductive tract, if any, were removed before weighing. The left-side humerus and femur bones were used to determine mineral content by bone-ash percentage and were stored at −80° until analysis. The bones were boiled at 100°C for 30 min before being manually cleaned of all soft tissue. Cleaned bones were dried in an oven (100°C) for 24-h and then dry-ashed in a muffle furnace at 700°C for 24-h. Ash content was expressed as a percentage of the dry bone weight.

Statistical Analysis

The experimental design was a randomized complete block design with treatments in a 2 × 3 factorial arrangement with 2 Ca premolt treatments and 3 low-energy molt diets. Cage location within the barn and initial BW were used as the blocking criteria. Each block had 6 cages to which the treatments were randomly distributed. Experiment 1 had 44 blocks and the cage containing 3 hens was the experimental unit, whereas experiment 2 had 11 blocks and the individual hen was the experimental unit. Data for both experiments were analyzed by ANOVA using JMP (version 6.0.3, SAS Institute Inc., Cary, NC). P-values < 0.05 were considered significant and $P < 0.10$ was considered a trend in all comparisons.

For both experiments, Ca treatment and block were used in the model during the Ca premolt treatment. During the molt and postmolt period, Ca treatment, molt diet, the 2-way interaction of Ca treatment by molt diet, and block were used in the model. Due to a difference in egg weight during the baseline period, this value was used as a covariate in all models. The effects of the Ca premolt treatments were assessed using the main effect of the Ca treatment from the ANOVA table, whereas the effects of the molt diets were assessed by Fisher's least significant difference. In experiment 2, data from each period were compared with baseline values using Dunnett's test.

RESULTS

Experiment 1 Baseline and Ca Premolt Periods: Performance and Egg-Quality Attributes

During the 2-wk baseline period, there were no differences in feed consumption, feed utilization, BW, egg production, egg mass, specific gravity, Haugh units, or egg components ($P > 0.05$; Table 2). Egg weight was lowest during baseline for the hens assigned to the coarse-Ca premolt treatment, followed by the WM molt diet ($P = 0.04$). During the Ca premolt treatment, there were no differences in feed consumption, feed utilization, BW, egg production, egg mass, egg weight, or egg components ($P > 0.05$; Table 3).

During Molt and Postmolt Periods for FW, SH, and WM Diets: Performance and Egg-Quality Attributes

During the molt period, the Ca premolt treatment did not affect feed consumption, BW, or egg weight (P

Table 2. Experiment 1: Comparison of responses of hens during the baseline period (hens at 85–87 wk of age)[1]

	Coarse[2,3]			Fine[2,3]				
Measure	FW	SH	WM	FW	SH	WM	SEM	*P*-value[4]
Feed consumption, g/d	96.3	96.9	98.0	96.2	95.7	98.0	1.35	0.76
Feed utilization, g:g	0.449	0.476	0.455	0.441	0.478	0.452	0.01	0.16
BW, kg	1.68	1.68	1.69	1.69	1.66	1.68	0.01	0.12
Egg production, %	66.6	70.1	69.6	64.9	69.5	67.9	2.10	0.46
Egg weight, g	64.8[ab]	65.6[a]	63.8[b]	65.4[a]	65.7[a]	65.1[a]	0.46	0.04
Egg mass, g	43.3	42.7	46.2	45.6	44.7	44.5	1.32	0.45
Specific gravity	1.076	1.077	1.076	1.075	1.076	1.076	0.001	0.62
Haugh units	76	76	78	78	76	77	1.42	0.68
Dry yolk, %	14.4	14.7	14.6	14.5	14.7	14.6	0.15	0.77
Dry albumen, %	6.99	6.78	6.82	6.87	6.89	6.84	0.08	0.59
Dry shell, %	8.26	8.31	8.58	8.47	8.42	8.29	0.09	0.12

[a,b]Means within a row without a common superscript differ ($P < 0.05$).

[1]Values are least squares means ± pooled SEM (n = 44).

[2]Calcium was supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or as an all-fine $CaCO_3$ mixed into a laying-hen diet for a 1-wk premolt Ca treatment.

[3]Three molting treatments were compared: feed withdrawal (FW), soybean hulls (SH), and wheat middlings (WM).

[4]*P*-value from the main effect of treatment.

> 0.05). However, the fine-Ca premolt treatment resulted in lower egg production and feed utilization and higher egg mass compared with that of the coarse-Ca premolt treatment hens during molt ($P < 0.001$; Table 4). Hens assigned to the FW molt diet had the lowest feed consumption, egg production, and egg mass. Hens fed the WM molt diet had the highest feed consumption, egg production, and BW and the lowest feed utilization during molt. However, there were no differences among the molt treatments in egg weight during molt ($P = 0.66$; Table 4).

Hens fed the FW molt diet, regardless of Ca premolt treatment, reached 0% egg production first, on d 8 of molt. Hens fed the coarse- or fine-Ca premolt treatment followed by the SH molt diet reached 0% egg production on d 19 and 21 of molt, respectively. Hens fed the coarse- or fine-Ca premolt treatments followed by the WM molt diet reached lows of 2.7 and 2.0% egg production on d 26 and 25 of molt, respectively. There were no significant interactions between the Ca premolt treatment and molt diets in this period.

First 2 wk Postmolt for FW, SH, and WM Diets: Performance and Egg-Quality Attributes

During the first 2 wk postmolt, the Ca premolt treatments had no effect on egg production, feed consumption, or BW ($P > 0.05$; Table 5). The molt diets during this first 2 wk postmolt had no effect on feed consumption ($P = 0.06$), but hens fed the WM molt diet had higher egg production and BW compared with those of the other 2 diets ($P < 0.001$).

Hens fed the fine- or coarse-Ca premolt treatments followed by the FW or WM molt diets reached 50% egg production by d 17 after molt. The hens fed the fine- or coarse-Ca premolt treatments followed by the SH molt diet reached 50% production by d 18 and 22 after molt,

Table 3. Experiment 1: Comparison of responses of hens during the Ca premolt treatment (hens at 87–88 wk of age)[1]

Measure	Coarse[2]	Fine[2]	SEM	*P*-value[3]
Feed consumption, g/d	98.7	97.1	1.31	0.13
Feed utilization, g:g	0.391	0.411	0.02	0.23
BW, kg	1.69	1.68	0.01	0.30
Egg production, %	63.9	63.5	2.17	0.81
Egg weight, g	65.5	65.5	0.53	0.98
Egg mass, g	42.5	42.6	1.36	0.94
Specific gravity	1.076	1.076	0.001	0.69
Dry yolk, %	15.4	15.2	0.21	0.26
Dry albumen, %	7.00	6.99	0.12	0.87
Dry shell, %	8.70	8.77	0.09	0.34

[1]Values are least squares means ± pooled SEM (n = 44).

[2]Calcium was supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or as an all-fine $CaCO_3$ mixed into a laying-hen diet for a 1-wk premolt Ca treatment.

[3]*P*-value from main effect of Ca premolt treatment; $P < 0.05$ was significant.

Table 4. Experiment 1: Comparison of responses of hens during the molt period (hens at 89–92 wk of age)[1]

	Calcium premolt[2]		Molt[3]				*P*-value[4]	
Measure	Coarse	Fine	FW	SH	WM	SEM	Ca	Molt
Feed consumption, g/d	36.7	36.0	26.1^{a}	34.0^{b}	48.9^{c}	0.95	0.37	<0.001
Feed utilization, g:g	0.691	0.557	0.713^{a}	0.701^{a}	0.457^{b}	0.02	<0.001	<0.001
BW, kg	1.39	1.38	1.37^{a}	1.35^{b}	1.45^{c}	0.01	0.19	<0.001
Egg production, %	10.4	8.41	7.22^{a}	8.86^{b}	12.1^{c}	0.58	<0.001	<0.001
Egg weight,[5] g	65.8	65.9	66.0	65.7	65.9	0.43	0.66	0.85
Egg mass,[5] g	19.6	23.0	22.8^{a}	24.0^{b}	22.9^{b}	0.97	<0.001	0.001

[a–c]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]Values are least squares means ± pooled SEM (n = 44).

[2]Calcium was supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or as an all-fine $CaCO_3$ mixed into a laying-hen diet for a 1-wk premolt Ca treatment.

[3]Three molting treatments were compared: feed withdrawal (FW), soybean hulls (SH), and wheat middlings (WM). The 7-d FW was followed by restricted (60 g/hen) skip-a-day feeding.

[4]*P*-values from main effect of Ca premolt treatment or molt diet.

[5]Egg weight and egg mass were only measured during the last week of molt due to low egg production.

respectively. There were no significant interactions between the Ca premolt treatment and molt diets in this period.

Last 20 wk Postmolt for FW, SH, and WM Diet: Performance and Egg-Quality Attributes

During the next 20 wk postmolt, the fine-Ca premolt treatment resulted in higher egg production ($P = 0.02$) and egg mass ($P = 0.01$) compared with that of the coarse-Ca premolt treatment, but there were no differences in feed utilization, BW, egg weight, specific gravity, Haugh units, or egg components, ($P > 0.05$). There tended ($P = 0.06$) to be an increase in feed consumed by hens provided the fine-Ca premolt treatment (Table 5). The hens fed the SH molt diet during the last 20 wk postmolt had the lowest ($P = 0.03$) feed consumption and BW ($P = 0.003$) compared with that of hens fed the FW and WM molt diets, but there were no differences in egg production, feed utilization, egg weight, egg mass, specific gravity, Haugh units, or egg components ($P > 0.05$; Table 5). There were no significant interactions between the Ca premolt treatment and molt diets in this period.

Total Postmolt Period (22 wk) for FW, SH, and WM Diets: Performance and Egg-Quality Attributes

Over the entire 22-wk postmolt period, the Ca premolt treatments had no effect on egg production, feed consumption, feed utilization, BW, or egg weight (Table 6; $P > 0.05$). However, hens fed the fine-Ca premolt

Table 5. Experiment 1: Comparison of responses of hens during the postmolt period (hens at 92–114 wk of age)[1]

	Calcium premolt[2]		Molt[3]				*P*-value[4]	
Measure	Coarse	Fine	FW	SH	WM	SEM	Ca	Molt
First 2 wk postmolt (92 wk of age)								
Feed consumption, g/d	91.6	92.0	92.2	93.4	89.8	1.47	0.70	0.06
BW, kg	1.44	1.44	1.45^{a}	1.37^{b}	1.50^{c}	0.01	0.84	<0.001
Egg production, %	5.19	4.82	0.89^{a}	0.93^{a}	13.2^{b}	1.16	0.70	<0.001
Last 20 wk postmolt (94 wk of age)								
Feed consumption, g/d	103.2	104.7	104.7^{a}	102.6^{b}	104.6^{a}	0.88	0.06	0.03
Feed utilization, g:g	0.480	0.491	0.490	0.486	0.479	0.01	0.20	0.58
BW, kg	1.71	1.72	1.72^{a}	1.69^{b}	1.73^{a}	0.01	0.23	0.003
Egg production, %	69.9	72.6	71.6	71.2	70.8	1.35	0.02	0.87
Egg weight, g	67.2	67.5	67.4	67.2	67.5	0.28	0.31	0.53
Egg mass, g	48.8	50.9	50.3	50.5	48.7	0.95	0.01	0.11
Specific gravity	1.081	1.081	1.081	1.081	1.080	0.0004	0.62	0.21
Haugh unit	80	80	80	80	79	0.84	0.79	0.26
Dry yolk, %	14.5	14.5	14.5	14.6	14.4	0.12	0.94	0.55
Dry albumen %	7.40	7.38	7.42	7.40	7.34	0.06	0.78	0.44
Dry shell, %	9.08	9.13	9.08	9.07	9.16	0.09	0.45	0.54

[a–c]Means within a row without a common superscript differ ($P < 0.05$).

[1]Values are least squares means ± pooled SEM (n = 44).

[2]Calcium was supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or as an all-fine $CaCO_3$ mixed into a laying-hen diet for a 1-wk premolt Ca treatment.

[3]Three molting treatments were compared: feed withdrawal (FW), soybean hulls (SH), and wheat middlings (WM).

[4]*P*-values from main effect of Ca premolt treatment or molt diet.

Table 6. The main effects of Ca premolt treatment and molt diets during the 22-wk postmolt period (hens at 92–114 wk of age) for production parameters of the laying hen[1]

	Calcium premolt[2]		Molt[3]				*P*-value[4]	
Measure	Coarse	Fine	FW	SH	WM	SEM	Ca	Molt
Feed consumption, g/d	97.4	98.4	98.4	98.0	97.2	1.00	0.25	0.47
Feed utilization, g:g	0.482	0.500	0.509	0.514	0.450	0.01	0.08	<0.001
BW, kg	1.57	1.58	1.58[a]	1.53[b]	1.61[c]	0.01	0.61	<0.001
Egg production, %	37.5	38.7	36.2[a]	36.1[a]	42.0[b]	0.88	0.11	<0.001
Egg weight, g	67.1	67.3	67.4	67.2	66.0	0.29	0.46	0.25
Egg mass, g	46.8	49.0	50.1[a]	50.3[a]	43.4[b]	1.18	0.02	<0.001

[a–c]Means within a row without a common superscript differ ($P < 0.05$).

[1]Values are least squares means ± pooled SEM (n = 44).

[2]Calcium was supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or as an all-fine $CaCO_3$ mixed into a laying-hen diet for a 1-wk premolt Ca treatment.

[3]Three molting treatments were compared: feed withdrawal (FW), soybean hulls (SH), and wheat middlings (WM).

[4]*P*-values from main effect of Ca premolt treatment or molt diet.

treatment had a higher ($P = 0.02$) egg mass compared with that of hens fed the coarse-Ca premolt treatment.

The molt treatments over the 22 wk postmolt did not affect feed consumption or egg weight ($P > 0.05$). Hens fed the WM molt diet had the highest egg production and BW and the lowest egg mass and feed utilization compared with those of the other 2 molt diets ($P < 0.001$). Hens fed the SH molt diet had the lowest BW compared with that of the other 2 molt diets during the 22 wk postmolt ($P < 0.001$; Table 6). There were 3, 0, 4, and 27 hen mortalities during the baseline period, Ca premolt treatment, molt period, and postmolt period, respectively. These hens are believed to have died for reasons unrelated to the treatments. There were no significant interactions between the Ca premolt treatment and molt diets in the overall period.

During Molt and Postmolt for FW, SH, and WM Diets: Economics

When comparing the Ca premolt treatments, the egg income was higher for the fine-Ca premolt treatment and resulted in a higher return-over-feed cost per hen housed compared with that of the coarse-Ca premolt treatment. For the molt diets, the egg income was highest for the WM molt diet and resulted in a higher profit per hen housed compared with that of the SH and FW molt diets. The FW molt diet had the lowest egg income, resulting in the lowest profits per hen housed (Table 7). There were no significant interactions between the Ca premolt treatment and molt diets.

Experiment 2 Baseline and Ca Premolt Periods: Physiology

The Ca premolt treatment resulted in no differences between the fine- or coarse-Ca premolt treatment values and baseline values in femur-ash percentage, plasma Ca concentrations, or ALP activity. However, hens that were fed the coarse-Ca premolt treatment had greater ovary and oviduct weights than hens during the baseline period, but there were no differences from hens provided the fine-Ca premolt treatment.

Table 7. The effect of Ca premolt treatment and molt diet on egg income minus feed costs (wk 1–29)

Treatment	Egg income,[1] $	Feed cost,[2] $	Profit, $	Profit per hen housed, $
Calcium premolt[3]				
Coarse	3,698.33	783.28	2,915.05	7.36
Fine	3,837.88	794.16	3,043.72	7.69
Molt[4]				
FW	2,456.07	345.23	2,110.84	7.94
SH	2,499.44	351.34	2,148.10	8.08
WM	2,580.70	355.05	2,225.65	8.37

[1]Egg income was based on 99.5 cents per dozen eggs produced obtained from Feedstuffs magazine (Chicago, Oct. 2008).

[2]Feed cost was obtained from Feedstuffs magazine (Chicago, Oct. 2008) based on feed consumption from wk 1 to 29 (layer diets and molt diets).

[3]In total, 396 hens per Ca premolt treatment were used. Calcium was supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or as an all-fine $CaCO_3$ mixed into a laying-hen diet for a 1-wk premolt Ca treatment.

[4]In total, 266 hens per molt treatment were used. Three molting treatments were compared: feed withdrawal (FW), soybean hulls (SH), and wheat middlings (WM). The 7-d FW was followed by restricted (60 g/hen) skip-a-day feeding.

Table 8. Comparison of responses of hens during each period for reproductive tract weights and bone ash-percentages from experiment 2[1]

Measure	Baseline	Calcium premolt[2] Coarse	Calcium premolt[2] Fine	Molt[3] FW	Molt[3] SH	Molt[3] WM	SEM	P-value[4] Ca	P-value[4] Molt
Ovary, g	41.3	—	—	—	—	—	1.95	—	—
Calcium premolt		50.9*	49.3	—	—	—	3.16	0.73	—
During molt		5.92*	5.60*	5.27*[ab]	4.51*[a]	7.50*[b]	1.66	0.74	0.03
Postmolt		42.3	48.3	45.8	42.9	47.3	3.62	0.06	0.49
Oviduct, g	52.1	—	—	—	—	—	5.19	—	—
Calcium premolt		66.4*	64.4	—	—	—	3.10	0.67	—
During molt		13.2*	12.2*	10.9*[a]	11.0*[a]	16.2*[b]	3.08	0.60	0.02
Postmolt		52.4	65.4*	61.2	55.1	60.3	4.09	0.001	0.31
Humerus bone, %	64.6	—	—	—	—	—	0.68	—	—
Calcium premolt		62.0	61.0*	—	—	—	3.43	0.52	—
During molt		61.0	61.7	61.7	60.8	61.7	0.96	0.36	0.56
Postmolt		62.2	61.5	61.7	61.6	62.3	1.50	0.85	0.57
Femur bone, %	55.2	—	—	—	—	—	1.42	—	—
Calcium premolt		55.1	54.6	—	—	—	1.02	0.75	—
During molt		51.5*	50.5*	50.9*	51.7	50.3*	1.06	0.22	0.39
Postmolt		52.9	53.3	53.2	52.5	53.6	1.55	0.72	0.79

[a,b]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]Values are least squares means ± pooled SEM (n = 9).

[2]Calcium was supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or as an all-fine $CaCO_3$ mixed into a laying-hen diet for a 1-wk premolt Ca treatment.

[3]Three molting treatments were compared: feed withdrawal (FW), soybean hulls (SH), and wheat middlings (WM).

[4]*P*-values from main effect of Ca premolt treatment or molt diet.

*Means within a row differ from baseline value ($P < 0.05$). *P*-value from Dunnett's comparison.

During the Ca premolt treatment, hens fed the fine-Ca premolt treatment had lower humerus-ash percentages and higher inorganic plasma P concentrations compared with those of hens during the baseline period, but there were no differences from baseline values for birds fed the coarse-Ca premolt treatment. There were no differences in ovary and oviduct weights, bone-ash percentage, or any blood parameters between the hens fed the Ca premolt treatments (Tables 8 and 9).

When comparing values from the Ca premolt treatments during molt to baseline values, hens fed the fine- or coarse-Ca premolt treatment had lower ovary and oviduct weights, femur-ash percentage, and plasma Ca concentrations and higher ALP activity ($P < 0.05$).

Table 9. Comparison of responses of hens during each period for the blood measures from experiment 2[1]

Measure	Baseline	Calcium premolt[2] Coarse	Calcium premolt[2] Fine	Molt[3] FW	Molt[3] SH	Molt[3] WM	SEM	P-value[4] Ca	P-value[4] Molt
H:L ratio,[5] %	40	—	—	—	—	—	0.04	—	—
Calcium premolt		45	41	—	—	—	0.09	0.59	—
During molt		42	46	42	44	46	0.04	0.36	0.59
After molt		47	40	46	43	41	0.04	0.01	0.42
Plasma Ca, mg/dL	29.6	—	—	—	—	—	2.27	—	—
Calcium premolt		33.1	35.0	—	—	—	4.27	0.58	—
During molt		13.7*	12.2*	11.4*[a]	11.3*[a]	16.2*[b]	2.06	0.39	0.03
After molt		31.5	32.3	32.2	33.8	29.5	1.74	0.61	0.06
Inorganic P, mg/dL	1.15	—	—	—	—	—	0.08	—	—
Calcium premolt		1.42	1.48*	—	—	—	0.08	0.58	—
During molt		1.06	1.01	0.96	1.07	1.09	0.05	0.36	0.16
After molt		1.32	1.36	1.33	1.41	1.23	0.10	0.42	0.64
ALP,[6] IU/L	32.4	—	—	—	—	—	5.04	—	—
Calcium premolt		32.4	58.0	—	—	—	9.60	0.58	—
During molt		71.6*	65.5*	62.2*	66.0*	77.4*	8.77	0.40	0.21
After molt		41.4	48.5*	45.0	50.4*	39.3	5.48	0.12	0.14

[a,b]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]Values are least squares means ± pooled SEM (n = 9).

[2]Calcium was supplied as a 50:50 mix of fine (0.14-mm mean diameter) and coarse (2.27-mm mean diameter) $CaCO_3$ or as an all-fine $CaCO_3$ mixed into a laying-hen diet for a 1-wk premolt Ca treatment.

[3]Three molting treatments were compared: feed withdrawal (FW), soybean hulls (SH), and wheat middlings (WM).

[4]*P*-values from main effect of Ca premolt treatment or molt diet.

[5]H:L = heterophil:lymphocyte ratio.

[6]ALP = alkaline phosphatase.

*Means within a row differ from baseline value ($P < 0.05$). *P*-value from Dunnett's comparison.

However, there were no differences in baseline values and Ca premolt treatment values during molt in humerus-ash percentage, inorganic plasma Ca concentration, or heterophil to lymphocyte ratios. There were no differences in ovary and oviduct weights, bone-ash percentages, or any blood parameters between the hens fed the Ca premolt treatments during molt ($P < 0.05$; Tables 8 and 9). There were no significant interactions between the Ca premolt treatment and molt diets in this period.

During Molt and Postmolt for FW, SH, and WM Diets: Physiology

Hens fed molt diets had lower ovary and oviduct weights and plasma Ca concentrations and higher ALP activity during molt compared with those of the baseline ($P < 0.05$). Hens fed the FW and WM molt diets had lower femur-ash percentages during molt compared with those of hens during the baseline period. There were no differences between humerus-ash percentages or inorganic plasma P concentrations during molt for hens fed any of the molt diets and hens during the baseline period (Tables 8 and 9).

When comparing the hens fed the molt diets during molt, hens fed the WM molt diet had greater ovary weights compared with those of hens fed the SH molt diet, but ovary weights of hens fed the WM or SH molt diets were not different from hens assigned to the FW treatment. Hens fed the WM molt diet had greater oviduct weights and higher plasma Ca concentrations compared with those of hens fed the FW and SH molt diets. There were no differences in bone-ash percentages, inorganic plasma P concentrations, or ALP activity among the hens assigned to the 3 molt diets during molt (Tables 8 and 9).

When comparing baseline values to postmolt values for hens fed the Ca premolt treatment, there were no differences in ovary weights, bone-ash percentages, plasma Ca concentrations, or inorganic plasma P concentrations. However, hens fed the fine-Ca premolt treatment had greater oviduct weights and higher ALP activity compared with those of hens during the baseline period, but there were no differences postmolt from hens during the baseline period when provided the coarse-Ca premolt treatment.

Postmolt, the hens fed the fine-Ca premolt treatment had heavier oviduct weights and there was a trend for heavier ovary weights compared with those of hens fed the coarse-Ca premolt treatment (Table 8). There were no differences postmolt in bone-ash percentages, plasma Ca and inorganic P concentrations, or ALP activity in hens fed the fine- or coarse-Ca premolt treatments (Table 9).

Hens fed the molt diets had no differences in ovary and oviduct weights or bone-ash percentages postmolt from hens during the baseline period. Hens fed the SH molt diet had higher ALP activity compared with that of hens during the baseline period, but none of the other blood parameters differed for hens fed the molt diets. When comparing hens fed the 3 molt diets, there were no differences postmolt in ovary and oviduct weights, bone-ash percentages, or any blood parameters (Tables 8 and 9). There were no significant interactions between the Ca premolt treatment and molt diets.

DISCUSSION

A national survey conducted in 1999 by the USDA Animal and Plant Health Inspection Service (USDA, 2000) reported that 74.2% of the farm sites surveyed molted their last completed flocks, whereas only 25.8% of the farm sites did not molt their last completed flock. Molting a flock results in one-third of the profits from that flock (Holt, 2003), as molting allows producers to avoid decreased profits by molting their hens during times of lower egg prices and avoiding spent flocks by keeping their hens for a second laying cycle with increased egg production and egg-quality postmolt. In the past, molt was induced in commercial laying hens by a period of feed withdrawal, but this method is no longer common practice in the United States due to concern for laying-hen well-being (United Egg Producers, 2008). However, a non-FW molt is less effective at inducing molt compared with the traditional FW (Biggs et al., 2004). Therefore, non-FW alternatives need to be improved and, in the present study, our objectives were to evaluate a Ca premolt treatment followed by low-energy molt diets or a 7-d FW.

Other than egg weight, there were no differences in any measures during the baseline period, which was expected because the laying hens were selected from a single source, considered to be in good health, and had not been subjected to any prior experimental treatments. Physiological parameters measured for the laying hens during baseline were considered to be in the normal ranges for the laying hen at this stage of her productive life (Biggs et al., 2004).

Calcium provided as coarse particles can improve eggshell quality and bone strength (Scott et al., 1982; Fleming et al., 1998; Scheideler, 1998; Whitehead and Fleming, 2000). The coarse Ca particles are solubilized more slowly from the gizzard than fine Ca particles, which allows the hen to absorb more dietary Ca from the small intestines at night during eggshell formation which can then result in less Ca mobilized from bone stores (Scott et al., 1971; Zhang and Coon, 1997; Whitehead, 2004). Calcium is also necessary for the release of gonadotropic hormones, including the surge in luteinizing hormone that results in ovulation necessary for egg production (Luck and Scanes, 1979, 1980; Johnson, 2000).

In the present study, we tested the hypothesis that a fine-Ca premolt treatment would result in a more efficient molt by causing a faster drop in egg production. Although the fine-Ca premolt treatment is not deficient in Ca, the hen may absorb less from the digestive tract and will be unable to meet the Ca needs for eggshell formation and maybe decrease the luteinizing-hormone surge necessary for ovulation. However, coarse Ca has been reported to decrease the possibility of osteoporosis in the laying hen (Fleming, 2008). During molt, estrogen levels drop, allowing osteoblasts to form structural bone that improves skeletal integrity (Whitehead, 2004). Calcium is needed during bone formation, and less intestinal absorption of Ca from fine Ca compared with Ca from coarse Ca may hinder the process of structural bone formation. Therefore, the effects of the fine-Ca premolt treatment on physiological parameters, such as bone-ash percentage and stress, were evaluated in the present study.

During the Ca premolt treatment, there were no differences in any production parameters or specific gravity of the egg. Deviating from the normal practice of feeding coarse Ca for only 1 wk did not appear to have immediate effects on eggshell quality or production and should not discourage producers from using the fine-Ca premolt program. There were also no differences seen in hens fed the 2 Ca premolt treatments for ovary and oviduct weights, bone-ash percentages, or blood measures during the Ca premolt treatment. However, when compared with those of hens during the baseline period, hens fed the coarse-Ca premolt treatment had higher ovary and oviduct weights. Calcium concentrations are correlated with ovary and oviduct weights (Mirarchi, 1993) and the coarse-Ca premolt treatment may allow more Ca absorption in the hen, resulting in the higher ovary and oviduct weights.

Plasma Ca and inorganic P concentrations and ALP activity can be used to assess molting effects on bone metabolism (Hurwitz and Griminger, 1961; Reichmann and Connor, 1977). Plasma Ca and P ions are removed from blood and deposited in bone tissue, with assistance from the enzyme ALP, for bone mineralization (Saladin, 2004). High plasma ALP activity and low Ca and P concentrations mean that Ca and P are being recruited for bone formation and may indicate bone disease (Saladin, 2004). The hens fed the fine-Ca premolt treatment had a lower humerus-ash percentage and a higher inorganic plasma P concentration during the Ca premolt treatment compared with those of hens during the baseline period. These results may have been caused by the need for Ca stores in bone to mobilize for eggshell formation, because the fine Ca does not stay in the digestive tract as long as the coarse Ca, resulting in reduced bone mineral content (Guinotte and Nys, 1991; Whitehead, 2004). However, plasma Ca concentrations and ALP activity did not differ from baseline values during the Ca premolt treatment for either treatment. These results suggest that bone damage during the Ca premolt treatment was minimal for either treatment (Chute et al., 1961; Whitehead, 2004).

During molt, the hens assigned to the fine-Ca premolt treatment had lower egg production compared with that of hens fed the coarse-Ca premolt treatment. These results suggest the coarse-Ca premolt treatment did not result in a complete molt and the fine-Ca premolt treatment was more effective at reducing egg production and inducing molt.

The FW molt diet was the most effective at decreasing egg production during molt (0% by d 8) regardless of the Ca premolt treatment. Hens assigned to the WM molt diet, regardless of the Ca premolt treatment, never reached 0% egg production, which suggests these hens did not go through a complete molt. Koelkebeck et al. (2006) and Biggs et al. (2004) also reported that hens fed WM molt diets did not reach 0% egg production, but this disagrees with Biggs et al. (2003) who reported that hens fed a WM diet resulted in 0% egg production by d 8 of molt. This cessation of egg production may be due to energy differences in the diets because Biggs et al. (2003) used a diet consisting of 95% WM and containing 1,900 kcal/kg of ME, whereas the 75% WM diet in the present study contained 2,198 kcal/kg of ME. The higher-energy diet used in the present study may be the cause for an incomplete cessation of egg production. Performance of the laying-hen postmolt is related to the degree of regression of the reproductive tract during molt, and an incomplete molt, such as observed with the WM molt diet, can be a concern for producers if it results in lower egg production and egg-quality postmolt (Ruszler, 1998).

The hens assigned to the FW molt treatment had the lowest egg production during molt, followed by the hens fed the SH and the hens fed the WM molt diets (the latter of which had the highest egg production). These findings agree with those of Biggs et al. (2003) and Koelkebeck et al. (2006), who both reported higher egg production during molt for hens fed a WM molt diet compared with that of hens assigned to a 10-d FW. The differences in egg production during molt may be due to the differences in feed consumption caused by novelty, palatability, or low energy contents of the diets (Biggs et al., 2003). The hens fed the WM molt diet had the lowest feed utilization and consumed the most feed (which was still about 50 g/hen per day less than it was during baseline) during molt. The hens assigned to the FW molt diet had the lowest feed consumption and egg mass compared with those of the other 2 molt diets. The lower feed consumption can be attributed to the limited feed provided during the skip-a-day feeding and the lower egg mass can be attributed to the low egg production of the hens assigned to the FW molt diet.

Body weight was highest during molt for hens fed the WM molt diet, which correlated with their higher feed consumption compared with that of the hens fed the SH and FW molt diets. The hens fed the FW molt diet had higher BW than the hens fed the SH molt diet and this increase may be due to the FW hens receiving a high-energy, high-protein diet every other day during the last 3 wk of molt. These results agree with Biggs et al. (2003), who reported BW loss was lowest for hens assigned to a WM molt diet or a 10-d FW compared with that of hens fed a corn molt diet and a 4-d FW.

Hens assigned to all treatments had lower ovary and oviduct weights compared with those of hens during the baseline period, which was expected due to the regression of the reproductive tract that occurred during molt (Berry, 2003). These results agree with Biggs et al. (2004), who reported that ovary and oviduct weights decreased during molt. In the present study, the hens fed the WM molt diet had the heaviest ovary weight compared with that of hens fed the SH molt diet and the heaviest oviduct weight compared with that of hens fed the FW or SH molt diets during the molt period. The higher weights for the hens fed the WM molt diet suggests their reproductive tract did not regress as fully as the hens fed the other molt diets.

Molt results in a rapid decrease in medullary bone and resumption of structural bone formation (Whitehead and Fleming, 2000). In the present study, the humerus-ash percentage was not different from baseline values for hens assigned to any of the treatments during molt. The humerus is a pneumatized bone rather than a medullary bone (Whitehead, 2004), so it may not be as affected when Ca stores are mobilized. However, the femur-ash percentage was lower than baseline values in hens fed the fine- or coarse-Ca premolt treatment followed by the FW or WM molt diets. Additionally, all treatments resulted in hens with lower plasma Ca concentrations during molt and higher ALP activity compared with baseline. Calcium is mobilized from medullary bone during egg production for the formation of the eggshell and, during molt, the drop in egg production results in lower plasma Ca concentrations (Whitehead, 2004).

The fine- and coarse-Ca premolt treatments had no effect on egg production, feed consumption, or BW during the first 2 wk postmolt, which suggests there are no immediate effects when returning to production. However, hens fed the fine-Ca premolt treatment had higher egg production and egg mass during the following 20 wk postmolt compared with that of the coarse-Ca premolt treatment, which suggests it was more effective at increasing production long-term after the molt period. Hens fed the fine-Ca premolt treatment also had higher egg mass during the entire 22 wk postmolt compared with that of the coarse-Ca premolt treatment and may be a result of increased egg production.

Hens fed the WM molt diet had higher egg production and BW compared with that of hens fed the other 2 molt diets during the first 2 wk postmolt, but egg production, egg weight, and egg mass did not differ during the following 20 wk postmolt. This increase in egg production and BW in hens fed the WM molt diet immediately following molt can be explained by the incomplete drop in egg production and BW during the molt period. The treatments had no effect on egg components, Haugh units, or specific gravity during the last 20 wk postmolt, which agrees with reports by Biggs et al. (2004), and suggests the treatments are comparable in their effects on egg quality after molt. Over the entire 22 wk postmolt, hens fed the WM molt diet had higher egg production compared with that of hens fed the other 2 diets, which may be a result of the higher egg production during the first 2 wk following molt.

Hens assigned to the FW and WM molt diets with the fine- or coarse-Ca premolt treatments were the first to reach 50% egg production (d 17 after molt). These results are similar to those reported by Koelkebeck et al. (2006) with hens fed WM and 10-d FW molt diets reaching 50% production by d 15 and 19, respectively. It is speculated that the hens fed the WM molt diet reached 50% egg production before the hens fed the SH molt diet because the WM molt diet did not result in a decrease in egg production as much during molt (12.1 and 8.9%, respectively).

For the physiological parameters, none of the Ca premolt treatments or molt diets affected bone-ash percentages or blood parameters after molt, and they did not differ from baseline values. These results suggest that any changes during molt are temporary, given that the levels return to premolt values. The only effect observed postmolt was in the oviduct weight which was higher for the hens fed the fine-Ca premolt treatment compared with that of hens fed the coarse-Ca premolt treatment and hens during the baseline period. There was a trend during molt for lower oviduct weights from hens fed the fine-Ca premolt treatment, which suggests this higher weight postmolt is due to a more complete regression of the reproductive tract.

The fine-Ca premolt treatment resulted in higher profits per hen housed compared with that of the coarse-Ca premolt treatment. When comparing the molt diets, the WM molt diet resulted in the highest profits per hen housed compared with profits of the FW and SH molt diets. The higher profit may be a result of higher egg production because the hens fed the WM molt diet did not decrease production during molt as much as the other treatments. The FW molt diet resulted in the lowest profits per hen housed. These hens had a 7-d FW followed by skip-a-day feeding; however, the diet was more nutritious with more protein and energy than the WM and SH molt diets, which makes it more expensive and was comparable in price to the other diets.

In conclusion, an all-fine $CaCO_3$ added to a laying-hen diet for 1 wk before molt appeared to be more efficient at inducing molt by causing a greater reduction in egg production during molt and higher egg production and oviduct weights after molt compared with that of the coarse Ca premolt treatment. Additionally, the fine-Ca premolt treatment did not appear to negatively affect bone-ash percentages or blood parameters and it resulted in a higher profit compared with that of the coarse-Ca premolt treatment. The fine-Ca premolt treatment was successful regardless of what molt diet was used. In agreement with previous research, the FW molt diet resulted in the most complete molt with a greater drop in egg production and BW but also resulted in less profits compared with the SH and WM molt diets. The SH molt diet was more effective at inducing molt compared with the WM molt diet by causing a greater reduction in egg production and ovary and oviduct weights during molt. Both low-energy diets, particularly SH, can be acceptable and profitable alternatives to FW molts.

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