

# AN INVESTIGATION OF DIFFERENT MOLTING TECHNIQUES WITH AN EMPHASIS ON ANIMAL WELFARE

**K. KESHAVARZ<sup>1</sup>**

*Department of Animal Science, 247 Morrison Hall,  
Cornell University, Ithaca, NY 14853  
Phone: (607) 255-8143  
FAX: (607) 255-9829  
e-mail: kk33@cornell.edu*

**F. W. QUIMBY**

*Department of Biomedical Sciences, Veterinary Medicine,  
Cornell University, Ithaca, NY 14853*

---

**Primary Audience:** Egg Producers, Researchers, Nutritionists, Feed Manufacturers

---

## SUMMARY

We experimented to evaluate the effect of a number of molting techniques that appeared to be less stressful than the conventional feed withdrawal (FW) method on postmolt performance. The molting techniques involved a continuous FW (T1, control group), 1 d FW followed by feeding a grape pomace (GP) diet containing 10 ppm thyroxine (T2) ad libitum, feeding a corn diet (T3) ad libitum, or the corn diet with an initial FW of 1 d (T4) or 2 d (T5), or regimens similar to T3, T4, and T5, respectively, in which the corn diet contained 10 ppm thyroxine (T6, T7, and T8). Induction of molting started at 66 wk of age and lasted until 30% body weight reduction (BWR) or 28 d—whichever came first. Postmolt performance information was collected up to 98 wk of age. The 30% BWR was obtained after 14 d FW with T1 and after 16 d FW with T2. Hens exposed to T6, T7, and T8 had a BWR of 26 to 29% after 28 d, and those exposed to T3, T4, and T5 had a BWR of 16 to 18% after 28 d from the start of induction of molt. Postmolt egg production (EP) was consistently greater for T1 and T2 than the other molting techniques. Other production traits, egg quality, and serum corticosterone, for the most part, were not different among various molting techniques. The results indicated that use of a GP diet plus thyroxine could support a similar postmolt performance as the conventional method of continuous FW. Unfortunately, the physiological response did not indicate that the use of a GP diet plus thyroxine was less stressful than the conventional method of continuous FW. Nevertheless, because use of the GP diet plus thyroxin supplies the hens continuously with some nutrients such as energy, protein, vitamins and minerals, etc., during induction of molt, this approach seems preferable due to ever-increasing public concern surrounding the hen welfare and the long duration of FW in a conventional FW technique.

**Key words:** corticosterone, grape pomace, laying hen, molting technique, thyroxine

2002 J. Appl. Poult. Res. 11:54–67

---

<sup>1</sup> To whom correspondence should be addressed.

## DESCRIPTION OF PROBLEM

Induction of molt after 1 yr of egg production (EP) is commonly practiced by the commercial egg industry to expand productivity of hens for a second laying cycle and to enhance albumen and shell quality, which normally deteriorate by the end of the first laying cycle. Investigation of various molting techniques, up to recent years, mainly emphasized the success of molting procedures on postmolt performance. Induction of molt by FW of various durations with or without water and photoperiod restrictions [1, 2, 3, 4], use of feed ingredients with low nutritional value such as grape pomace (GP) [5] or guar meal [2], dietary manipulation of certain minerals such as zinc [6, 7], iodine [8], sodium [9, 10], chloride [10], Ca [11], aluminum [12], and copper [6], or the use of anti-ovulatory drugs [13], among others techniques, have resulted in satisfactory postmolt performance. Nevertheless, FW of various durations, with or without water and photoperiod restriction up to a body weight reduction (BWR) of about 30%, is the most commonly used technique by the industry due to ease of application, economic advantage, and satisfactory postmolt performance [14]. However, during recent years, due to public concern surrounding animal welfare, the suitability of FW for the induction of molt has been seriously questioned. Because of the economic significance of induction of molt to the poultry industry, other molting techniques that would reduce or eliminate the FW period warrant further investigation.

In order to address animal welfare concerns, efforts have been made by many investigators to reduce or eliminate the FW period of a molting program. McCormick and Cunningham [15] reported that postmolt EP performance was significantly greater for hens exposed to 10-d FW than for hens fed 20,000 ppm zinc for 4 or 8 d. Koelkebeck et al. [4] reported that a FW of less than 10 d might yield satisfactory EP and egg weight (EW), but shell quality could be enhanced by using FW of 10 d or longer. In a previous study [16], an effort was made to determine whether the FW period could be satisfactorily reduced from the conventional 10 to 14 d down to 5 to 7 d. The results indicated that postmolt EP and shell quality of hens subjected to 10-to-14-d FW were superior compared to

those subjected to 5-to-7-d FW. Consistent with this report, Kuney and Bell [17] reported higher EP for hens exposed to 10 to 14 d FW than those exposed to 4 d FW. More recently, Bell [18] from the results of a large study involving 440,000 hens, five strains, and five experiments, concluded that the FW systems were generally superior to other molting techniques. Nevertheless, from the results of that study Bell [18] concluded that other molting techniques, such as the use of a "no-salt diet" for 28 d at the rate of 45 to 55 g/hen per d, have the potential for use in the future when more attention is given to the problems of applying controlled feeding principles equally to all hens. It is worth noting the "no-salt diet" used in the study of Bell [18] consisted of corn that was fortified with limestone, dicalcium phosphate and a grower-layer vitamin-mineral mixture that contained 0.8% calcium and 0.4% nonphytate phosphorus.

On the other hand, several investigators observed no differences in EP of hens exposed to 4 and 10 d of FW [19, 20] or observed better EP for hens exposed to 4-d FW than those exposed to 10-d FW [21]. Zimmermann et al. [2] reported that hens that were molted by receiving a complete layer diet for 6 h on every third, fourth, and fifth recurring day (corresponding to 25 d and about 8 cycles, 22 d and about 5.5 cycles, and 19 d and about 4 cycles, respectively) lose about 31 to 33% of their BW after 19 to 25 d and maintain a satisfactory postmolt performance. Also, inclusion of 15% guar meal to a layer diet and providing the hens with this diet ad libitum resulted in a loss of 31% BW in 20 d with a quite satisfactory postmolt performance.

In a subsequent experiment [22], the effect of feeding of three diets (ground corn, 22% CP starter, or 15% CP layer diet) ad libitum for exactly 6 h on every third, fourth, and fifth recurring day on postmolt performance was investigated. Approximately 30% BWR was attained after 23, 20, and 17 d of limited feeding of these diets on every third, fourth, and fifth recurring day, respectively. Satisfactory postmolt production performance was obtained with all treatments, and neither the type of diet used during the 6-h limited feeding (ground corn, 22% CP starter, or 15% CP layer diet) nor the period of limited-time feeding used to induced molt (every third, fourth, and fifth recurring day) was of any

long-term importance. The investigators concluded that molt induced by limited feeding is an acceptable alternative to induction of molt by a continuous FW technique.

Buhr and Cunningham [23] exposed the hens to three feeding regimens of complete FW, daily feeding of a low-density, low-energy molt diet at 22.8 g/hen per d, or by limited alternate-day feeding of this diet at 45.5 g/hen until 15, 20, or 25% BWR had resulted. Postmolt mortality and EP were not different as the result of molt induction method or percentage BW loss. Therefore, information obtained from the work of Zimmermann et al. [2], Zimmermann and Andrews [22], and Buhr and Cunningham [23] indicated that the potential exists to minimize the period of FW in a molting program and still obtain postmolt performance comparable to that observed with the conventional method of FW for about 10 to 14 d to obtain approximately 30% BWR.

Due to the ever-increasing public concern surrounding animal welfare, the current experiment was conducted to evaluate a number of molting techniques that, although their application could be practical and have the potential of a satisfactory postmolt performance, would be less stressful than 10-to-14-d FW. The molting techniques used in the current study either did not involve a FW period or the period of FW was reduced to 1 or 2 d. Additionally, the molt diets were supplemented with adequate levels of calcium and phosphorus to satisfy these nutrient requirements for developing pullets from 12 to 18 wk of age [24]. Furthermore, the molting diets were fortified with adequate sodium, chloride, and vitamins and minerals similar to levels that are normally used by the industry in commercial layer diets. Water deprivation or photoperiod reduction was not considered as a part of the molting techniques used in the current study.

## MATERIALS AND METHODS

Four hundred eighty, 66-wk-old Babcock B300 hens were used in this experiment. The hens were kept in a high-rise, three-deck, windowless house equipped with deep cages (38.1 cm wide × 50.8 cm deep). Each experimental replicate consisted of 15 birds located in three adjacent cages with 5 birds per cage. Four such

replicates made an experimental treatment. Based on 2-wk pre-experimental EP, 3-d pre-experimental EW, and BW at the start of the experiment, treatment means for these traits were similar ( $P > 0.05$ ) at the start of the experiment. The experiment ran from 66 to 98 wk of age. The first 4 wk (66 to 70 wk of age) were used for induction of molt by using various techniques, and the subsequent seven periods of 4 wk (70 to 98 wk) were allocated to collection of production data for comparing the effect of various molting techniques. The experiment started in early August 1998 and was completed the middle of March 1999.

The effects of eight molting techniques were studied in this experiment (Table 1). Treatment 1 (T1) used a conventional FW period until about 30% BWR had occurred and served as the control. The hens on T2 were subjected to 1-d FW and then were fed a GP diet containing 10 ppm thyroxine (Table 2) ad libitum until about 30% BWR had occurred. Hens on T3 were fed a corn diet ad libitum until 30% BWR had occurred (Table 2). Hens on T4 and T5 were subjected to 1 or 2 d FW, respectively, followed by being fed a corn diet ad libitum until 30% BWR had occurred. Hens on T6, T7, and T8 were treated similarly to hens on T3, T4, and T5, respectively, with the exception that a corn diet was supplemented with 10 ppm thyroxine. Thyroxine was used in some of the treatments to accelerate the rate of BW loss and to reduce the period needed to reach 30% BWR [25]. The GP and corn diets were supplemented with limestone and monocalcium phosphate to maintain adequate levels of calcium and nonphytate phosphorus (NPP) in these diets for a pullet developer diet from 12 to 18 wk of age (Table 2) [24]. Additionally, the GP and corn diets were supplemented with adequate levels of sodium, chloride, and vitamins and minerals similar to the levels that normally are used in commercial layer diets. At the end of each induced molt, hens were fed the Cornell layer-breeder diet ad libitum until the end of the experiment (98 wk of age; Table 2).

Records of daily EP and weekly feed intake (FI) were kept throughout the experiment. All eggs produced during the last three consecutive days of each 4-wk collection cycle (starting from 74 wk of age) were saved for measurement of EW and egg sizes (according to the USDA grad-

TABLE 1. Description of molting techniques

TREATMENT	DESCRIPTION
T1	Continuous FW <sup>A</sup> until 30% BWR, <sup>B</sup> then feeding ad libitum on a layer diet.
T2	1 d FW followed by feeding ad libitum on a GP <sup>C</sup> diet containing 10 ppm thyroxine until 30% BWR, then, feeding ad libitum on a layer diet.
T3	Continuously on a corn diet until 30% BWR, then feeding ad libitum on a layer diet.
T4	1 d FW, then continuously on a corn diet until 30% BWR, then feeding ad libitum on a layer diet.
T5	2 d FW, then continuously on a corn diet until 30% BWR, then feeding ad libitum on a layer diet.
T6	As T3, with 10 ppm added thyroxine.
T7	As T4, with 10 ppm thyroxine.
T8	As T5, with 10 ppm added thyroxine.

<sup>A</sup>Feed withdrawal.

<sup>B</sup>Body weight reduction.

<sup>C</sup>Grape pomace.

ing system). Specific gravity (SG) was determined on the same eggs used for the measurement of EW and egg sizes. A random sample of eight eggs from each replicate (and on every 8-wk basis, corresponding to Weeks 74, 82, 90, and 98) was saved for measurement of albumen height and Haugh units. These measurements were made the day following when the eggs were saved. Body weights of sample birds from each treatment were determined several times during induced molt (66 to 70 wk of age) to determine the approximate age at which 30% BWR occurred. The hens were also weighed at the end of their respective molting technique, at 74 wk of age, and at the end of the experiment (98 wk of age). Records of mortality were kept throughout the study. Water was provided ad libitum during molt induction and postmolt. Daily photoperiod was kept at 16 h light throughout the experiment because the treatments were intermingled.

At the end of each molting technique (Days 14 and 16 for T1 and T2, respectively, and Day 28 for the other regimens), blood samples were taken from the brachial veins of two random hens per replicate (eight hens/treatment) for determination of hematocrit and serum corticosterone. Every effort was made to handle the birds gently during removal from the cages and during blood sampling. It took approximately 120 to 150 s from the time that the bird handler reached into the cage to completion of blood sampling. Thereafter, one of the birds used for blood sampling was randomly selected and killed by CO<sub>2</sub>

gas for determining ovary and oviduct weight and oviduct length. The ovary and oviduct weights were determined by removing them from the bird and weighing them on a digital scale, measuring to 0.1 g precision. Oviduct length was determined by carefully laying it flat on a table and accurately measuring its length within 0.1 mm.

On the same day that blood samples were taken from birds on T1 (Day 14), blood samples were also taken from eight hens that were not part of the experiment but were the same age and were kept in a similar type of cage and bird density as the experimental groups, but were not subjected to molting (i.e., were kept continuously on feeding ad libitum of the Cornell layer-breeder diet), for comparison of corticosterone and hematocrit values.

Specific gravity was measured by using 12 salt solutions varying in SG from 1.058 to 1.102, in increments of 0.004 U. Blood sample was removed from the brachial vein with a 5-mL syringe and 23-ga needle. The blood sample was then poured into a 10-mL test tube. The microcapillary tube was then inserted into the test tube to draw off a sample for hematocrit reading. The remaining blood sample was used for separation of serum. Serum corticosterone was measured with a commercial double antibody radioimmunoassay kit [26]. A marketable sample of four to five eggs was collected from the thyroxine-fed groups after 24 and 48 h (T2, T7, and T8) and after 24, 48, 72, and 96 h (T3) of feeding thyroxine-containing diets for determining the

TABLE 2. Composition of experimental diets

INGREDIENT	CORN DIET <sup>A</sup> (%)	GRAPE POMACE DIET <sup>B,C</sup> (%)	CORNELL LAYER-BREEDER DIET (%)
Corn	96.60	5.00	63.10
Grape pomace	—	91.30	—
Soybean meal, dehulled (48% CP)	—	—	22.20
Corn distillers grains + solubles	—	—	1.50
Alfalfa meal	—	—	1.00
DL-Methionine	—	—	0.10
Salt	0.34	0.38	0.35
Limestone	1.62	1.50	4.50
Oyster shell	—	—	4.00
Mono-dicalcium phosphate	1.04	1.42	1.50
Vitamin mixture <sup>D</sup>	0.25	0.25	—
Mineral mixture <sup>E</sup>	0.15	0.15	—
Vitamin-mineral mixture <sup>F</sup>	—	—	0.25
Blended fat	—	—	1.50
CALCULATED ANALYSIS <sup>G</sup>			
Energy (kcal/kg)	3,245	1,597	2,849
Protein (%)	7.30	7.00	16.80
Lysine (%)	0.26	0.29	0.84
Methionine (%)	0.16	0.11	0.35
Total sulfur amino acids (%)	0.32	0.22	0.65
Calcium (%)	0.8	1.31	3.56
Nonphytate phosphorus (%)	0.3	0.32	0.42
Sodium (%)	0.15	0.23	0.17

<sup>A</sup>Based on determined protein value of 7.5% in corn.

<sup>B</sup>The results of proximate analysis of grape pomace (GP) indicated that it contained 9.2% moisture, 7.2% crude protein, 10.3 fat, and 20.9% crude fiber. At the start of the experiment, no information about the nutrient composition of GP was available to us. We assumed the levels of various nutrients, with the exception of determined protein value (7.2%), are very small and negligible in GP. Consequently, adequate levels of limestone, mono-dicalcium phosphate, and salt were added to the GP diet to make the levels of Ca, NPP, and sodium in the GP diet identical to levels of these nutrients in the corn diet (i.e., Ca = 0.8%, NPP = 0.3%, and Na = 0.15%). However, recently and after completion of the experiment, we were able to find information about the nutrient composition of the GP in the United States-Canadian Tables of Feed Composition [35]. The nutrient content of the GP diet in Table 2 is based on taking the nutrient content of GP [35] into consideration.

<sup>C</sup>A premix consisting of 5 kg corn, 0.38 kg salt, 1.5 kg limestone, 1.42 kg mono-dicalcium phosphate, 0.25 kg vitamin mixture, and 0.15 kg mineral mixture was made prior to mixing it with 91.3 kg GP for 100 kg of diet, in order to ensure that small ingredients were uniformly distributed in the finished feed.

<sup>D</sup>Vitamin mixture provided the following per kilogram of diet: vitamin A (retinyl acetate), 8,800 IU; cholecalciferol, 2,200 IU; DL- $\alpha$ -tocopheryl acetate, 11 IU; menadione sodium bisulfite, 2.2 mg; riboflavin, 4.4 mg; D-calcium pantothenate, 8.8 mg; nicotinic acid, 44 mg; pyridoxine hydrochloride, 2.2 mg; folic acid, 0.55 mg; d-biotin, 0.11 mg; thiamine hydrochloride, 2.5 mg; vitamin B<sub>12</sub>, 6.6  $\mu$ g; choline, 220 mg; ethoxyquin, 125 mg.

<sup>E</sup>Mineral mixture provided the following per kilogram of diet: Mn, 60 mg; Zn, 50 mg; Fe, 30 mg; Cu, 5 mg; I, 1.06 mg; Se, 0.1 mg.

<sup>F</sup>Vitamin and mineral mixture provided the following per kilogram of diet: vitamin A (retinyl acetate), 6,600 IU; cholecalciferol, 2,200 IU; DL- $\alpha$ -tocopheryl acetate, 11 IU; menadione sodium bisulfite, 2.2 mg; riboflavin, 4.4 mg; D-calcium pantothenate, 15.4 mg; nicotinic acid, 44 mg; pyridoxine hydrochloride, 1.1 mg; folic acid, 0.22 mg; d-biotin, 0.22 mg; thiamine, 0.44 mg; vitamin B<sub>12</sub>, 11  $\mu$ g; choline, 275 mg; ethoxyquin, 66 mg; Mn, 80 mg; Zn, 88 mg; Fe, 22 mg; Cu, 11 mg; I, 0.22 mg; Se, 0.11 mg.

<sup>G</sup>According to NRC [24] tables of feed composition, except GP, which composition was based on the tables of United States-Canadian tables of feed composition [34].

concentration of thyroxine in the egg and the potential for marketability of such eggs. Also, a sample of eggs was collected from the other groups that were on full-fed, thyroxine-free diet for comparison of their thyroxine levels with those of birds fed the thyroxine-containing diets.

Total thyroxine content of the yolk of each egg was measured with a commercially available solid phase radioimmunoassay kit [27].

Data were analyzed by ANOVA using SAS software [28], and means were compared by Duncan's multiple-range test [29]. This study

was conducted according to an institutional animal care and use committee (IACUC)-approved protocol in a facility accredited by the Association for Assessment and Accreditation of Laboratory Animal Care [30].

## RESULTS AND DISCUSSION

Birds on the conventional FW regimen (T1) lost 30.8% of their BW after 14 d, and birds on GP plus thyroxine (T2) lost 30.3% of their BW after 16 d from the beginning of molt induction (Table 3). Other molt-inducing techniques did not produce a 30% BWR, even when the birds were kept on their respective molt regimens for 28 d. The presence of thyroxine in the corn diet accentuated the rate of BWR. Hens fed the corn diet plus thyroxine lost 27 to 29% of their BW in 28 d compared to 16 to 18% BWR for hens fed only corn diet (T3, T4, and T5 vs. T6, T7, and T8). Feed withdrawal for 1 or 2 d before feeding the corn diet with or without thyroxine had no effect ( $P > 0.05$ ) in accentuating the extent of BWR (T3 vs. T4 and T5; T6 vs. T7 and T8). At 74 wk of age, hens on the conventional FW regimen (T1) had regained all of their lost BW. The BW of hens on other molt regimens were still less at 74 wk of age than the beginning BW at 66 wk of age. At this age, BW of hens on the continuous FW regimen were significantly heavier than those fed the corn diet containing thyroxine and exposed to 1 or 2 d FW (T1 vs. T7 and T8;  $P < 0.05$ ). At the end of the experiment (98 wk of age), BW were not significantly different among various molt programs, although they were noticeably less for hens fed the corn diet containing thyroxine and exposed to 1 or 2 d FW (T7 and T8) than the birds on other molt regimens.

Birds on continuous FW or GP plus thyroxine regimens (T1 and T2) went out of production 3 to 4 d after the initiation of molt (during Week 67), which continued until the middle of Week 70 (Table 4). With other molt regimens, EP was greatly reduced during Week 67 and was reduced further during Week 68; however, EP of these groups never reached 0, even at Week 69 or 70. Similar to BW, the presence of thyroxine in the corn diet enhanced the rate of decline in EP. The average EP for Weeks 67 to 70 was significantly lower for hens fed the corn diet

TABLE 3. The effect of different molting techniques on body weight during the experiment (66 to 98 wk of age)

MOLT REGIMEN	BW AT 66 WK (g)	BW AT END OF MOLT (g)	BW LOSS DURING MOLT (g)	TARGET BWR <sup>A</sup> (%)	ACTUAL BWR (%)	DAYS TO BWR	BW AT 74 WK (g)	BW AT 98 WK (g)	BW CHANGES (66 to 98 wk) (g)
T1 Continuous FW <sup>B</sup>	1,563 <sup>a</sup>	1,082 <sup>b</sup>	481 <sup>b</sup>	30	30.8 <sup>a</sup>	14	1,629 <sup>a</sup>	1,813 <sup>a</sup>	250 <sup>a</sup>
T2 1 d FW + GP <sup>C</sup> + T4 <sup>D</sup>	1,576 <sup>a</sup>	1,099 <sup>b</sup>	477 <sup>b</sup>	30	30.3 <sup>a</sup>	16	1,500 <sup>ab</sup>	1,753 <sup>a</sup>	177 <sup>a</sup>
T3 Continuous corn diet	1,552 <sup>a</sup>	1,272 <sup>a</sup>	280 <sup>a</sup>	30	18.1 <sup>b</sup>	28	1,503 <sup>ab</sup>	1,696 <sup>a</sup>	144 <sup>a</sup>
T4 1 d FW + corn diet	1,583 <sup>a</sup>	1,326 <sup>a</sup>	257 <sup>a</sup>	30	16.2 <sup>b</sup>	28	1,562 <sup>ab</sup>	1,753 <sup>a</sup>	170 <sup>a</sup>
T5 2 d FW + corn diet	1,557 <sup>a</sup>	1,287 <sup>a</sup>	269 <sup>a</sup>	30	17.3 <sup>b</sup>	28	1,553 <sup>ab</sup>	1,811 <sup>a</sup>	255 <sup>a</sup>
T6 Continuous corn diet + T4	1,587 <sup>a</sup>	1,165 <sup>b</sup>	422 <sup>b</sup>	30	26.5 <sup>a</sup>	28	1,511 <sup>ab</sup>	1,726 <sup>a</sup>	139 <sup>a</sup>
T7 1 d FW + corn diet + T4	1,568 <sup>a</sup>	1,118 <sup>b</sup>	450 <sup>b</sup>	30	28.6 <sup>a</sup>	28	1,379 <sup>b</sup>	1,633 <sup>a</sup>	65 <sup>a</sup>
T8 2 d FW + corn diet + T4	1,560 <sup>a</sup>	1,140 <sup>b</sup>	420 <sup>b</sup>	30	26.8 <sup>a</sup>	28	1,440 <sup>b</sup>	1,542 <sup>a</sup>	-18 <sup>a</sup>
Pooled SEM	31	26	28	1.5	1.5	56	79	86	

<sup>a,b</sup>Means within columns with no common superscripts differ significantly ( $P < 0.05$ ).

<sup>A</sup>Body weight reduction.

<sup>B</sup>Feed withdrawal.

<sup>C</sup>Grape pomace.

<sup>D</sup>T4 = Thyroxine.

TABLE 4. The effect of molt regimens on egg production during first 4 wk after initiation of molt (66 to 70 wk of age)

MOLT REGIMEN	EGG PRODUCTION (%)						MORTALITY (66 to 70 wk)	
	Pre-experiment <sup>A</sup>	Week 67	Week 68	Week 69	Week 70	66 to 70 wk	n	%
T1 Continuous FW <sup>B</sup>	73.6 <sup>a</sup>	18.9 <sup>bc</sup>	0.0 <sup>d</sup>	0.0 <sup>d</sup>	11.1 <sup>ab</sup>	7.5 <sup>c</sup>	2/60	3.3 <sup>ab</sup>
T2 1 d FW + GP <sup>C</sup> + T4 <sup>D</sup>	73.1 <sup>a</sup>	15.0 <sup>c</sup>	0.0 <sup>d</sup>	0.0 <sup>d</sup>	4.8 <sup>c</sup>	5.0 <sup>c</sup>	0/60	0.0 <sup>b</sup>
T3 Continuous corn diet	73.3 <sup>a</sup>	34.8 <sup>a</sup>	9.7 <sup>bc</sup>	10.9 <sup>b</sup>	9.8 <sup>b</sup>	16.3 <sup>ab</sup>	0/60	0.0 <sup>b</sup>
T4 1 d FW + corn diet	73.2 <sup>a</sup>	34.1 <sup>a</sup>	17.3 <sup>a</sup>	20.5 <sup>a</sup>	14.9 <sup>a</sup>	21.8 <sup>a</sup>	5/60	8.3 <sup>a</sup>
T5 2 d FW + corn diet	73.5 <sup>a</sup>	23.3 <sup>bc</sup>	13.6 <sup>ab</sup>	17.8 <sup>a</sup>	10.5 <sup>ab</sup>	16.3 <sup>b</sup>	2/60	3.3 <sup>ab</sup>
T6 Continuous corn diet + T4	73.5 <sup>a</sup>	27.1 <sup>ab</sup>	4.3 <sup>cd</sup>	5.0 <sup>c</sup>	2.4 <sup>c</sup>	9.7 <sup>c</sup>	0/60	0.0 <sup>b</sup>
T7 1 d FW + corn diet + T4	73.3 <sup>a</sup>	24.5 <sup>bc</sup>	3.1 <sup>d</sup>	4.6 <sup>c</sup>	1.5 <sup>c</sup>	8.4 <sup>c</sup>	0/60	0.0 <sup>b</sup>
T8 2 d FW + corn diet + T4	73.1 <sup>a</sup>	19.3 <sup>bc</sup>	1.9 <sup>d</sup>	2.4 <sup>c</sup>	2.2 <sup>c</sup>	6.5 <sup>c</sup>	1/60	1.7 <sup>b</sup>
Pooled SEM	3.1	3.0	2.0	2.0	1.6	1.5		2.1

<sup>a-d</sup>Means within columns with no common superscript differ significantly ( $P < 0.05$ ).

<sup>A</sup>Egg production during the pre-experimental period (65 and 66 wk of age).

<sup>B</sup>Feed withdrawal.

<sup>C</sup>Grape pomace.

<sup>D</sup>T4 = Thyroxine.

continuously or with 1 or 2 d FW with thyroxine in the diet, as opposed to corn alone (T3, T4, and T5 vs. T6, T7, and T8). This finding is consistent with the report of Sekimoto et al. [25] that high dose injection of thyroxine (500  $\mu\text{g}/\text{kg}$  BW) reduced luteinizing hormone and progesterone in blood and induced molt. Egg production of hens on the continuous FW or on GP plus thyroxine were not significantly different than those fed the corn diet plus thyroxine with or without 1 or 2 d FW during 67 to 70 wk of age (T1 and T2 vs. T6, T7, and T8). However, the pattern of EP during this 4-wk period was different for the birds of the former than the latter groups, with birds in groups T1 and T2 making a dramatic increase following complete cessation of EP (Week 70).

Mortality was relatively low during molt induction for all of the molting regimens. The only exception was the mortality of hens on 1 d FW plus the corn diet (T4), in which mortality was somewhat higher than for birds on other molting techniques.

Birds on the continuous FW regimen (T1) had an average FI of about 105 g/hen per d during the first 2 wk after 30% BWR (Days 14 to 28; Table 5). Feed intake on the GP plus thyroxine (T2) averaged at 24 g/hen per d during molt induction (Days 2 to 16) and 106 g/hen per d during Days 16 to 28 when they received the layer diet ad libitum. FI during molt induction

for other regimens (T3, T4, T5, T6, T7, and T8) varied between 45 to 67 g/hen per d and was lower for hens on the corn diet with than without thyroxine (T3, T4, and T5 vs. T6, T7, and T8).

Serum corticosterone levels of hens on the control treatment that were always on an ad libitum feeding program were unexpectedly and significantly higher ( $P < 0.05$ ) than for hens on any other molting regimen (Table 6). Considering that every corticosterone value shown in Table 6 is the average of eight hens and that all the corticosterone values were consistently higher for the birds of the control-fed group (ad libitum) than the values of birds on various molting regimens, this higher value, in fact, is a valid observation, although the reason is not clear.

Beuving [31] has provided convincing evidence that laying hens manipulated in some way, such as handling, immobilization, withdrawal of feed and water, and exposure to high environmental temperatures, each have two- to sixfold increases in blood corticosterone concentrations. However, in the current study as was mentioned before, every effort was made to handle the birds gently during their removal from the cage and during the process of blood sampling. Consequently, it does not seem that stress imposed on hens during blood sampling contributed to the higher corticosterone level of birds on ad libitum feeding than birds on various molting regimens.

TABLE 5. The effect of molting techniques on feed intake during the first 4 wk after initiation of molt (66 to 70 wk of age)

TREATMENT	FEED INTAKE <sup>A</sup> (g/hen/d)	FEED INTAKE <sup>B</sup> (g/hen/d)	DESCRIPTION OF DIET
T1 Continuous FW <sup>C</sup>	105.4 (d 14 to 28)	52.7	Layer diet
T2 1 d FW + GP <sup>D</sup> + T4 <sup>E</sup>	24.2 (d 2 to 16) 106.1 (d 16 to 28)	58.4	GP plus T4 Layer diet
T3 Continuous corn diet	57.3 (d 1 to 28)	57.3	Corn diet
T4 1 d FW + corn diet	66.7 (d 2 to 28)	64.3	Corn diet
T5 2 d FW + corn diet	61.5 (d 3 to 28)	57.1	Corn diet
T6 Continuous corn diet + T4	46.5 (d 1 to 28)	46.5	Corn diet plus T4
T7 1 d FW + corn diet + T4	48.3 (d 2 to 28)	46.6	Corn diet plus T4
T8 2 d FW + corn diet + T4	45.3 (d 3 to 28)	52.1	Corn diet plus T4

<sup>A</sup> Daily feed intake only on the feeding days and according to the type of feed used (66 to 70 wk of age).

<sup>B</sup> Average daily feed intake for the entire 28 d (66 to 70 wk of age), regardless of the type of feed used or the number of days on feed.

<sup>C</sup> Feed withdrawal.

<sup>D</sup> Grape pomace.

<sup>E</sup> T4 = Thyroxine.

However, it is probable that handling the birds of various molting techniques several times during molt induction for determining the extent of BWR could have conditioned them to handling, which might have been a reason for their lower blood corticosterone levels than birds on a feeding program ad libitum.

Because corticosterone level was not significantly different among various molting regimens, it appears that the extent of stress was similar for various molt regimens used in this

experiment. Hematocrit values were highest for hens on continuous FW, were intermediate for hens on the GP and corn diets containing thyroxine, and were lowest for hens on the control-fed group (ad libitum) and hens on the corn diet without thyroxine (Table 6).

According to Sturkie [32] the loss of estrogenic activity could result in increased production of erythrocytes. Brake et al. [33] reported that starvation (forced molting) increased packed cell volume. Gilbert [34] reported that

TABLE 6. The effect of molting techniques on corticosterone and hematocrit levels

MOLT REGIMEN	DAY OF BLOOD SAMPLING	CORTICOSTERONE (ng/ml)	HEMATOCRIT (%)
Control <sup>A</sup>	14	9.15 <sup>a</sup>	33.8 <sup>c</sup>
T1 Continuous FW <sup>B</sup>	14	5.72 <sup>b</sup>	44.1 <sup>a</sup>
T2 1 d FW + GP <sup>C</sup> + T4 <sup>D</sup>	16	5.82 <sup>b</sup>	39.8 <sup>b</sup>
T3 Continuous corn diet	28	4.13 <sup>b</sup>	34.5 <sup>c</sup>
T4 1 d FW + corn diet	28	4.43 <sup>b</sup>	32.4 <sup>c</sup>
T5 2 d FW + corn diet	28	5.49 <sup>b</sup>	32.4 <sup>c</sup>
T6 Continuous corn diet + T4	28	4.18 <sup>b</sup>	39.1 <sup>b</sup>
T7 1 d FW + corn diet + T4	28	4.49 <sup>b</sup>	40.3 <sup>b</sup>
T8 2 d FW + corn diet + T4	28	3.50 <sup>b</sup>	40.1 <sup>b</sup>
Pooled SEM		0.77	0.8

<sup>a-c</sup> Means within columns with no common superscript differ significantly ( $P < 0.05$ ).

<sup>A</sup> Blood samples were taken from eight hens that were fed ad libitum for comparison of corticosterone and hematocrit values. These birds were not part of the experiment but were of the same age as the experimental groups and were kept in similar cages and bird density (five hens/cage) as the experimental groups. Blood samples were taken from hens of the control group one time only; the same day that blood samples were taken from hens on continuous FW regimen (Day 14).

<sup>B</sup> Feed withdrawal.

<sup>C</sup> Grape pomace.

<sup>D</sup> T4 = Thyroxine.

TABLE 7. The effect of molt regimens on ovary and oviduct weights and oviduct length at the end of the induction of molt techniques

MOLT REGIMEN	OVARY WEIGHT (g)	OVIDUCT WEIGHT (g)	OVIDUCT LENGTH (cm)
T1 Continuous FW <sup>A</sup>	3.1 <sup>b</sup>	10.4 <sup>b</sup>	31 <sup>bc</sup>
T2 1 d FW + GP <sup>B</sup> + T4 <sup>C</sup>	2.9 <sup>b</sup>	8.4 <sup>b</sup>	29 <sup>c</sup>
T3 Continuous corn diet	4.2 <sup>b</sup>	15.7 <sup>ab</sup>	35 <sup>bc</sup>
T4 1 d FW + corn diet	25.2 <sup>a</sup>	43.3 <sup>a</sup>	61 <sup>a</sup>
T5 2 d FW + corn diet	13.1 <sup>b</sup>	41.3 <sup>a</sup>	52 <sup>ab</sup>
T6 Continuous corn diet + T4	8.8 <sup>b</sup>	31.2 <sup>ab</sup>	43 <sup>abc</sup>
T7 1 d FW + corn diet + T4	15.5 <sup>ab</sup>	39.1 <sup>a</sup>	50 <sup>abc</sup>
T8 2 d FW + corn diet + T4	11.8 <sup>b</sup>	27.8 <sup>ab</sup>	36 <sup>bc</sup>
Pooled SEM	3.8	8.5	7

<sup>a-c</sup>Means within columns with no common superscripts differ significantly ( $P < 0.05$ ).

<sup>A</sup>Feed withdrawal.

<sup>B</sup>Grape pomace.

<sup>C</sup>T4 = Thyroxine.

thyroxine causes erythropoietic activity (increased production of red blood cells). This information collectively suggests that the rate of decline in EP (Table 4) and reduced estrogenic activity were major factors for the hematocrit pattern observed during use of various molting techniques in the current experiment. Dietary thyroxine was apparently also a contributing factor. Overall, the data indicate a positive relationship among the severity of reduced FI and BWR, decreased EP during the period of induction of molt, and elevation of hematocrit values.

With the exception of birds on the continuous corn diet (T3), ovary and oviduct weight and length were greatest for birds fed the corn diet without thyroxine (T4 and T5), intermediate for birds fed the corn diet plus thyroxine (T6, T7 and T8), and least for birds on continuous FW and those fed GP with thyroxine (T1 and T2; Table 7). This information suggests a positive relationship between the rate of decline in EP (during molt induction) and a decrease in the size of these organs. The largest ovary and oviduct weight and oviduct length of groups fed the corn diet with or without thyroxine (with the exception of T3) indicated that these molting techniques were not effective in causing a sufficient regression of reproductive organs essential for satisfactory postmolt performance.

Egg production for 70 to 98 wk of age or 66 to 98 wk of age and egg mass (EM) and feed conversion (FC) for the period of 70 to 98 wk of age, for the most part, were not significantly different among various molting techniques (Ta-

ble 8). However, these traits were consistently greater for the birds on continuous FW or birds on GP plus thyroxine than other molting techniques (T1 and T2 vs. T3, T4, T5, T6, T7, and T8). In fact, for the postmolt period (70 to 98 wk of age), EP of birds on T1 and T2 were about 9 to 11% greater than the average EP for birds on other molting regimens (T3, T4, T5, T6, T7, and T8). Use of a limited number of replicates with only 15 hens each in the current experiment (four replicates) was probably the reason that these relatively large differences in EP were not significant. In fact, McKeen [5] has reported that induction of molt by offering hens GP ad libitum for 10, 14, or 18 d results in a postmolt performance comparable to those exposed to 10 d FW, as was observed in the current experiment. Egg weight, FI, and egg grade classifications were not significantly different among various molting techniques. At no time were SG of eggs from birds on continuous FW significantly greater than SG of eggs from birds on other molting regimens (Table 9). The only exception was at 78 wk of age when SG was significantly greater for hens on continuous FW than for hens fed a corn diet after FW for 1 or 2 d (T1 vs. T4 and T5). Similarly, Haugh units and albumen height of eggs from birds on continuous FW, for the most part, were not significantly higher than birds on other molting regimens (Table 10). The only exceptions were at 90 wk of age and for the entire experiment, in which these values were significantly greater for hens on the contin-

TABLE 8. The effect of molting techniques on egg production performance during postmolt (70 to 98 wk of age)

MOLT REGIMEN	EGG PRODUCTION (70 to 98 wk)		EGG WEIGHT <sup>A</sup> (g)	EGG MASS <sup>A</sup> (g)	FEED CONSUMPTION <sup>A</sup> (g/hen/day)	FEED CONVERSION <sup>A</sup> (g:g)	MORTALITY (66 to 98 wk) (%)	EGG SIZE <sup>A,B</sup>		
	(%)	(%)						Large and above (%)	Medium (%)	Small and pee wee (%)
T1 Continuous FW <sup>C</sup>	75.3 <sup>a</sup>	66.8 <sup>a</sup>	61.6 <sup>a</sup>	46.4 <sup>a</sup>	112.1 <sup>a</sup>	2.44 <sup>b</sup>	11.7 <sup>a</sup>	77.6 <sup>a</sup>	20.5 <sup>a</sup>	1.8 <sup>a</sup>
T2 1 d FW + GP <sup>D</sup> + T4 <sup>E</sup>	73.2 <sup>ab</sup>	64.7 <sup>a</sup>	61.2 <sup>a</sup>	44.7 <sup>a</sup>	110.9 <sup>a</sup>	2.49 <sup>ab</sup>	6.7 <sup>a</sup>	73.0 <sup>b</sup>	26.2 <sup>a</sup>	0.8 <sup>a</sup>
T3 Continuous corn diet	62.6 <sup>b</sup>	56.9 <sup>a</sup>	63.3 <sup>a</sup>	39.6 <sup>a</sup>	108.4 <sup>a</sup>	2.79 <sup>ab</sup>	11.7 <sup>a</sup>	82.6 <sup>a</sup>	15.9 <sup>a</sup>	1.3 <sup>a</sup>
T4 1 d FW + corn diet	63.6 <sup>b</sup>	58.3 <sup>a</sup>	62.0 <sup>a</sup>	39.4 <sup>a</sup>	111.0 <sup>a</sup>	2.91 <sup>a</sup>	18.3 <sup>a</sup>	77.1 <sup>a</sup>	21.7 <sup>a</sup>	0.9 <sup>a</sup>
T5 2 d FW + corn diet	66.0 <sup>ab</sup>	59.8 <sup>a</sup>	61.9 <sup>a</sup>	40.9 <sup>a</sup>	110.8 <sup>a</sup>	2.76 <sup>ab</sup>	10.0 <sup>b</sup>	76.7 <sup>a</sup>	22.9 <sup>a</sup>	1.0 <sup>a</sup>
T6 Continuous corn diet + T4	64.1 <sup>ab</sup>	57.3 <sup>a</sup>	62.1 <sup>a</sup>	39.7 <sup>a</sup>	110.7 <sup>a</sup>	2.95 <sup>a</sup>	6.7 <sup>a</sup>	78.7 <sup>a</sup>	21.4 <sup>a</sup>	0.5 <sup>a</sup>
T7 1 d FW + corn diet + T4	64.0 <sup>ab</sup>	57.1 <sup>a</sup>	62.1 <sup>a</sup>	39.7 <sup>a</sup>	109.4 <sup>a</sup>	2.88 <sup>ab</sup>	6.7 <sup>a</sup>	73.3 <sup>a</sup>	26.7 <sup>a</sup>	0.1 <sup>a</sup>
T8 2 d FW + corn diet + T4	67.8 <sup>ab</sup>	60.2 <sup>a</sup>	61.2 <sup>a</sup>	41.6 <sup>a</sup>	109.1 <sup>a</sup>	2.88 <sup>ab</sup>	10.0 <sup>b</sup>	69.2 <sup>a</sup>	29.5 <sup>a</sup>	0.6 <sup>a</sup>
Pooled SEM	3.5	3.1	0.8	2.1	1.7	0.14	4.2	5.0	4.8	0.7

<sup>ab</sup>Means within columns with no common superscripts differ significantly ( $P < 0.05$ ).

<sup>A</sup>For 70 to 98 wk of age.

<sup>B</sup>Eggs with weight of 56.7 g/egg and greater were considered as large and above, 49.6 to 56.6 g/egg were considered as medium, and less than 49.6 g/egg were considered as small and pee wee.

<sup>C</sup>Feed withdrawal.

<sup>D</sup>Grape pomace.

<sup>E</sup>T4 = Thyroxine.

TABLE 9. The effect of molting techniques on specific gravity of eggs during postmolt period (74 to 98 wk of age)

MOLT REGIMEN	SPECIFIC GRAVITY AT DIFFERENT SAMPLING AGES							
	74 wk	78 wk	82 wk	86 wk	90 wk	94 wk	98 wk	Average
T1 Continuous FW <sup>A</sup>	1.0765 <sup>a</sup>	1.0766 <sup>a</sup>	1.0780 <sup>ab</sup>	1.0753 <sup>ab</sup>	1.0725 <sup>ab</sup>	1.0713 <sup>abc</sup>	1.0690 <sup>ab</sup>	1.0742 <sup>ab</sup>
T2 1 d FW + GP <sup>B</sup> + T4 <sup>C</sup>	1.0760 <sup>a</sup>	1.0758 <sup>abc</sup>	1.0784 <sup>ab</sup>	1.0746 <sup>ab</sup>	1.0713 <sup>ab</sup>	1.0721 <sup>abc</sup>	1.0677 <sup>ab</sup>	1.0737 <sup>ab</sup>
T3 Continuous corn diet	1.0752 <sup>a</sup>	1.0748 <sup>ab</sup>	1.0784 <sup>ab</sup>	1.0741 <sup>ab</sup>	1.0708 <sup>ab</sup>	1.0708 <sup>bc</sup>	1.0687 <sup>ab</sup>	1.0732 <sup>ab</sup>
T4 1 d FW + corn diet	1.0754 <sup>a</sup>	1.0736 <sup>bc</sup>	1.0770 <sup>b</sup>	1.0752 <sup>ab</sup>	1.0709 <sup>ab</sup>	1.0725 <sup>abc</sup>	1.0679 <sup>ab</sup>	1.0732 <sup>ab</sup>
T5 2 d FW + corn diet	1.0744 <sup>a</sup>	1.0730 <sup>c</sup>	1.0762 <sup>b</sup>	1.0723 <sup>b</sup>	1.0698 <sup>b</sup>	1.0694 <sup>c</sup>	1.0674 <sup>b</sup>	1.0718 <sup>b</sup>
T6 Continuous corn diet + T4	1.0755 <sup>a</sup>	1.0778 <sup>ab</sup>	1.0781 <sup>ab</sup>	1.0749 <sup>ab</sup>	1.0722 <sup>ab</sup>	1.0725 <sup>abc</sup>	1.0699 <sup>ab</sup>	1.0744 <sup>ab</sup>
T7 1 d FW + corn diet + T4	1.0740 <sup>a</sup>	1.0771 <sup>a</sup>	1.0782 <sup>ab</sup>	1.0742 <sup>ab</sup>	1.0721 <sup>ab</sup>	1.0733 <sup>ab</sup>	1.0699 <sup>ab</sup>	1.0741 <sup>ab</sup>
T8 2 d FW + corn diet + T4	1.0748 <sup>a</sup>	1.0760 <sup>abc</sup>	1.0808 <sup>a</sup>	1.0764 <sup>a</sup>	1.0741 <sup>a</sup>	1.0746 <sup>a</sup>	1.0709 <sup>a</sup>	1.0754 <sup>a</sup>
Pooled SEM	0.0008	0.001	0.001	0.001	0.0011	0.001	0.001	0.0008

<sup>a-c</sup>Means within columns with no common superscript differ significantly ( $P < 0.05$ ).

<sup>A</sup>Feed withdrawal.

<sup>B</sup>Grape pomace.

<sup>C</sup>T4 = Thyroxine.

uous FW regimen than for those fed the corn diet after being exposed to 1-d FW (T1 vs. T4).

The thyroxine content of a marketable egg sample of four to five eggs that were collected from the thyroxine-fed groups after 24 and 48 h (T2, T7, and T8) and after 24, 48, 72, and 96 h (T3) of feeding thyroxine-containing diets are shown in Table 11. Thyroxine levels were also measured in 30 eggs from the control group (full-fed, thyroxine-free diet). No detectable level of thyroxine ( $<0.5 \mu\text{g}/100 \text{ mL}$  yolk) was found in the yolk of the control group. Consequently, the thyroxine values in Table 11 are the transferrable thyroxine from the diets to yolk. The values, for the most part, were consistently increased with the length of feeding thyroxine-containing diets.

The presence of thyroxine in the yolk probably makes eggs unmarketable when produced by hens fed the thyroxine-containing diet during the first few days after induction of molt.

The primary objective of the current experiment was to compare the effect of various molting methods that appeared to be less stressful than the conventional FW approach on postmolt performance. Induction of molt by the conventional FW approach or by FW for 1 d followed by feeding ad libitum of GP containing 10 ppm thyroxine resulted in a 30% BWR within a reasonable period (14 or 16 d, respectively). With the other molting techniques, either the 30% BWR was not achieved even when hens were kept on their molting programs for 28 d (groups

TABLE 10. The effect of molting techniques on albumen height and Haugh units of eggs during postmolt period (74 to 98 wk of age)

MOLT REGIMEN	ALBUMEN HEIGHT					HAUGH UNIT				
	74 wk	82 wk	90 wk	98 wk	Average	74 wk	82 wk	90 wk	98 wk	Average
T1 Continuous FW <sup>A</sup>	7.05 <sup>a</sup>	7.33 <sup>a</sup>	7.21 <sup>a</sup>	6.93 <sup>ab</sup>	7.13 <sup>a</sup>	75.4 <sup>ab</sup>	73.0 <sup>a</sup>	71.0 <sup>a</sup>	71.4 <sup>a</sup>	72.7 <sup>a</sup>
T2 1 d FW + GP <sup>B</sup> + T4 <sup>C</sup>	7.50 <sup>a</sup>	7.35 <sup>a</sup>	6.83 <sup>ab</sup>	6.73 <sup>ab</sup>	7.10 <sup>a</sup>	77.2 <sup>a</sup>	73.8 <sup>a</sup>	69.0 <sup>a</sup>	73.1 <sup>a</sup>	73.3 <sup>a</sup>
T3 Continuous corn diet	7.33 <sup>a</sup>	7.18 <sup>a</sup>	6.98 <sup>ab</sup>	6.68 <sup>b</sup>	6.79 <sup>ab</sup>	74.0 <sup>ab</sup>	71.8 <sup>a</sup>	67.8 <sup>ab</sup>	68.3 <sup>a</sup>	70.5 <sup>ab</sup>
T4 1 d FW + corn diet	6.68 <sup>a</sup>	6.60 <sup>a</sup>	6.46 <sup>b</sup>	6.05 <sup>ab</sup>	6.45 <sup>b</sup>	72.4 <sup>b</sup>	67.1 <sup>a</sup>	61.9 <sup>b</sup>	69.2 <sup>a</sup>	67.6 <sup>b</sup>
T5 2 d FW + corn diet	6.68 <sup>a</sup>	7.08 <sup>a</sup>	6.71 <sup>ab</sup>	6.30 <sup>ab</sup>	6.74 <sup>ab</sup>	73.3 <sup>ab</sup>	70.8 <sup>a</sup>	66.3 <sup>ab</sup>	70.0 <sup>a</sup>	70.1 <sup>ab</sup>
T6 Continuous corn diet + T4	6.30 <sup>a</sup>	6.75 <sup>a</sup>	6.89 <sup>ab</sup>	7.20 <sup>a</sup>	6.79 <sup>ab</sup>	71.2 <sup>b</sup>	67.6 <sup>a</sup>	68.3 <sup>a</sup>	71.0 <sup>a</sup>	69.5 <sup>ab</sup>
T7 1 d FW + corn diet + T4	7.15 <sup>a</sup>	6.73 <sup>a</sup>	6.98 <sup>ab</sup>	6.70 <sup>ab</sup>	6.89 <sup>ab</sup>	72.8 <sup>ab</sup>	69.5 <sup>a</sup>	68.9 <sup>a</sup>	70.6 <sup>a</sup>	70.5 <sup>ab</sup>
T8 2 d FW + corn diet + T4	7.28 <sup>a</sup>	6.68 <sup>a</sup>	7.10 <sup>a</sup>	6.55 <sup>ab</sup>	6.90 <sup>ab</sup>	77.5 <sup>ab</sup>	68.7 <sup>a</sup>	69.7 <sup>a</sup>	70.8 <sup>a</sup>	71.7 <sup>ab</sup>
Pooled SEM	0.39	0.24	0.19	0.43	0.17	1.5	2.2	2.0	2.7	1.3

<sup>a,b</sup>Means within columns with no common superscript differ significantly ( $P < 0.05$ ).

<sup>A</sup>Feed withdrawal.

<sup>B</sup>Grape pomace.

<sup>C</sup>T4 = Thyroxine.

TABLE 11. Thyroxine content of the egg yolks after feeding thyroxine-containing diets<sup>A</sup>

TREATMENT	DAYS FED THYROXINE-CONTAINING DIETS			
	Day 1	Day 2	Day 3	Day 4
	(µg thyroxine/100 mL yolk)			
T2	2.136 ± 0.288 (5) <sup>B</sup>	2.276 ± 0.440 (5)	No marketable eggs <sup>D</sup>	No marketable eggs
T6	2.460 ± 0.383 (5)	2.252 ± 1.204 (5)	8.580 ± 2.988 (5)	11.256 ± 3.108 (5)
T7	0.756 ± 1.032 (5) <sup>C</sup>	3.076 ± 3.384 (5)	No marketable eggs	No marketable eggs
T8	1.414 ± 0.956 (4)	2.908 ± 0.728 (5)	No marketable eggs	No marketable eggs

<sup>A</sup>Mean ± SD.<sup>B</sup>Values in parenthesis are the number of eggs used for analysis.<sup>C</sup>Three out of five eggs had no detectable (ND) thyroxine. The detection limit was 0.10 µg/100 mL of yolk. Means and SD were based on assigning each of the ND thyroxine yolks a value of 0.000 µg.<sup>D</sup>Either no eggs were produced or the eggs that were produced had very poor shell quality for handling.

fed the corn diet with or without 1 or 2 d FW) or approximately such level of BWR was obtained only after 28 d of being kept on their molting programs (groups fed the corn diet containing thyroxine with or without 1 and 2 d FW). With most of the latter molting techniques, the reproductive organs (ovary and oviduct) did not regress adequately, which appears to be important for sustaining a satisfactory postmolt performance.

Egg production for the postmolt period (70 to 98 wk of age) or for molt plus postmolt periods (66 to 98 wk of age) were consistently, but for the most part not significantly, lower for birds exposed to various molting techniques as compared to birds on the conventional FW method (Table 8). The only exception was EP of the group fed the GP and thyroxine-containing diet, which values remained comparable to those on the continuous FW regimen (T1 vs. T2). For the most part, EW, egg sizes, FI, SG, albumen height and Haugh units, and mortality during the postmolt period were not significantly different among various molting techniques. Serum corticosterone level was not different among the various molting techniques used. Apparently, the main reason for the not significant, but consistent, reduction in egg production of birds on various molting techniques as compared to those of T1 and T2 was the time required for BWR (28 d) and the insufficient regression of reproductive organs, even after 28 d of molt induction. The

gradual withdrawal of nutrients from the body during the extended molt induction apparently made it impossible for birds to restore their body nutrient reserves sufficiently to support a comparable postmolt EP.

Among the molting techniques studied in the current experiment, induction of molt by 1 d FW followed by feeding a diet ad libitum of GP with thyroxine until 30% BWR appeared to be the most promising approach with regard to postmolt performance and hen welfare. With this method, postmolt performance was comparable to the conventional FW technique; a reasonable period was required for loss of 30% of BW (16 d). During the period of molt induction, hens had free access to a feed that was fortified with adequate calcium and nonphytate phosphorus to satisfy the requirement for these nutrients during the growing period and adequate sodium, chloride, vitamins and minerals were available to satisfy the requirement for these nutrients during the laying period.

It is worth noting that we did not study the significance of considering 1 d FW at the initiation of implementation of this molting technique or adding thyroxine to GP for success of this program. It is possible that the success of this molting technique would not require 1 d of FW or adding thyroxine to the GP diet. As was mentioned before, McKeen [5] reported that feeding GP freely for 10 to 18 d with or without vitamin and mineral supplementation resulted in induc-

tion of molt, with postmolt performance (for 40 wk) comparable to those exposed to 10 d FW. Buhr and Cunningham [23] reported that providing the hens with 22.8 g of a low-density, low-energy, molting diet on a daily basis or 45.5 g of this feed on an every-other-day basis until 15, 20, and 25% BWR, provided satisfactory postmolt performance comparable to birds on the conventional FW approach. Providing hens with a certain quantity of feed on a daily or alternate-day basis, as suggested by Buhr and Cunningham [23], makes application of this

method questionable in commercial practice, due to the use of automatic feeding systems, length of poultry houses for accommodation of large-sized flocks, and multiple-hen cages with hens of different social rank within a cage. In those areas where GP is not readily available, the approach suggested by Zimmermann and Andrews [22] of feeding a complete layer diet for 6 h and preferably on an every-third-recurring day until 30% BWR seems to be a promising approach, from an animal welfare point of view and for its practical application.

---

## CONCLUSIONS AND APPLICATIONS

1. A 1-d FW followed by feeding ad libitum of a GP diet containing 10 ppm thyroxine and fortified with calcium and nonphytate phosphorus adequate to satisfy the requirement of the growing pullets, and sodium, chloride, and vitamins and trace minerals adequate to satisfy the requirement of the laying hens, resulted in a comparable postmolt performance to the conventional FW technique.
  2. Accessibility to GP and adequate storage space for this rather light, low-density ingredient are among the factors that should be taken into consideration for application of this alternative molting technique for large commercial flocks of laying hens.
  3. In those places where GP is not available, use of other feedstuffs such as guar meal, which has been used successfully [2], can be considered as an alternative approach.
- 

## REFERENCES AND NOTES

1. Baker, M., J. Brake, and G.R. McDaniel, 1983. The relationship between body weight loss during an induced molt and post-molt egg production, egg weight, and shell quality in cage layers. *Poult. Sci.* 62:409–413.
2. Zimmermann, N.G., D.K. Andrews, and J. McGinnis, 1987. Comparison of several induce molting methods on subsequent performance of Single Comb White Leghorn hens. *Poult. Sci.* 66:408–417.
3. Bell, D.D., and D.R. Kunej, 1992. Effect of fasting and post-fasting diets on performance in molted flocks. *J. Appl. Poult. Res.* 1:200–206.
4. Koelkebeck, K.W., C.M. Parsons, R.W. Leeper, and J. Moshtaghian, 1992. Effect of duration of fasting on post-molt laying hen performance. *Poult. Sci.* 71:434–439.
5. McKeen, W.D., 1984. Feeding grape pomace to Leghorn hens as an alternative to starvation to induce a molt. *Poult. Sci.* 63(Suppl.):148–149. (Abstr)
6. Stevenson, M.H., and N. Jackson, 1984. Comparison of dietary hydrated copper sulfate, dietary zinc oxide, and a direct method for inducing a moult in laying hens. *Br. Poult. Sci.* 25:505–517.
7. Berry, W.D., and J. Brake, 1985. Comparison of parameters associated with molt induced by fasting, zinc, and low dietary sodium in cage layers. *Poult. Sci.* 64:2027–2036.
8. Arrington, L.R., R.A. Santa Cruz, R.H. Harms, and H.R. Wilson, 1967. Effects of excess dietary iodine upon pullets and laying hens. *J. Nutr.* 92:325–330.
9. Whitehead, C.C., and D.W.F. Shannon, 1974. The control of egg production using a low-sodium diet. *Br. Poult. Sci.* 15:429–434.
10. Harms, R.H., 1991. Effect of removing salt, sodium, or chloride from the diet of commercial layers. *Poult. Sci.* 70:333–336.
11. Gilbert, A.B., and R. Blair, 1975. A comparison of the effects of two low calcium diets on egg production in the domestic fowl. *Br. Poult. Sci.* 16:547–552.
12. Hussein, A.S., A.H. Cantor, and T.H. Johnson, 1989. Comparison of the use of dietary aluminum with the use of feed restriction for force-molting of laying hens. *Poult. Sci.* 68:891–896.
13. Wilson, R.H., J.S. Moore, A.W. O'Steen, J.L. Fry, and R.H. Harms, 1969. Forced molting of laying hens. Bulletin 728. University of Florida, Gainesville, FL.
14. Brake, J., 1993. Recent advances in induced molting. *Poult. Sci.* 72:929–931.
15. McCormick, C.C., and D.L. Cunningham, 1984. High dietary zinc and fasting as methods of force resting: A performance comparison. *Poult. Sci.* 63:1201–1206.
16. Keshavarz, K., 1995. Impact of feed withdrawal and dietary calcium level on force-rested hens. *J. Appl. Poult. Res.* 4:254–264.
17. Kunej, D.R., and D.D. Bell, 1989. Effect of molt duration on performance. Proc. of California Poultry Symposium. University of California, Riverside, CA.
18. Bell, D.D., 2001. Flock friendly molting methods—Alternatives to feed removal. *Cornell Poultry Pointers* 51(3):11–13.

19. **Cunningham, D.L., and C.C. McCormick**, 1985. A multicycle comparison of dietary zinc and feed removal molting procedures: Production and income performance. *Poult. Sci.* 64:253–260.
20. **McCormick, C.C., and D.L. Cunningham**, 1987. Performance and physiological profiles of high dietary zinc and fasting as methods of inducing a force rest. A direct comparison. *Poult. Sci.* 66:1007–1013.
21. **Christmas, R.B., R.H. Harms, and O.M. Junqueira**, 1985. Performance of Single Comb White Leghorn hens subjected to 4- or 10-day feed withdrawal force-rest procedures. *Poult. Sci.* 64:2321–2324.
22. **Zimmermann, N.G., and D.K. Andrews**, 1990. Performance of laying hens induced to molt by limited feeding of diets varying in nutrient density. *Poult. Sci.* 69:1883–1891.
23. **Buhr, R.J., and D.L. Cunningham**, 1994. Evaluation of molt induction to body weight loss of fifteen, twenty, or twenty-five percent by feed removal, daily-limited, or alternate-day feeding of a molt feed. *Poult. Sci.* 73:1499–1510.
24. **National Research Council**, 1994. *Nutrient Requirements of Poultry*. 9th rev. ed. Natl. Acad. Sci. Press, Washington, DC.
25. **Sekimoto, K., K. Imai, M. Suzuki, H. Takikawa, N. Hoshino, and K. Totsuka**, 1987. Thyroxine-induced molting and gonadal function of laying hens. *Poult. Sci.* 66:752–756.
26. **Diagnostic Products Corp.**, Los Angeles, CA.
27. **ICN Biomedicals**, Costa Mesa, CA. Yolks were separated, 1 to 2 drops of EDTA were added to prevent bacterial contamination, and yolks were stored at 4 C until assay. Initially a single yolk specimen was diluted 1:1, 1:4, 1:8, 1:16, and 1:32 with phosphate-buffered saline, and exactly 24  $\mu\text{g}$  of thyroxine was added to 100  $\mu\text{L}$  of each dilution. These serial dilutions were made to find the dilution necessary to document 100% of added thyroxine to yolk without subsequent inhibition of thyroxine binding by other yolk components. A dilution of 1:4 was the lowest, which provided adequate quantitation of added thyroxine. All yolk thyroxine concentrations ( $\mu\text{g}/100$  mL yolk) were recorded from 1:4 dilutions.
28. **SAS Institute**, 1988. *SAS/STAT User's Guide*. Release 6.03 Edition. SAS Institute Inc., Cary, NC.
29. **Duncan, D.B.**, 1955. Multiple range and multiple F tests. *Biometrics* 11:11–42.
30. **FASS**, 1999. *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching*. 1st rev. ed. Federation of Animal Science Societies, Savoy, IL.
31. **Beuving, G.**, 1980. *Corticoides in laying hens. The Laying Hen and Its Environment*. R. Moss, ed. Martinus Nijhoff, Boston, MA.
32. **Sturkie, P.D.**, 1976. *Avian Physiology*. 3rd ed. Springer-Verlag, New York, NY.
33. **Brake, J., M. Baker, G.W. Morgan, and P. Thaxton**, 1982. Physiological changes in caged layers during a force molt. Leukocytes and packed cell volume. *Poult. Sci.* 61:790–795.
34. **Gilbert, A.B.**, 1963. The effect of estrogen and thyroxine on blood volume of the domestic cock. *J. Endocrinol.* 26:41–47.
35. **NRC**, 1982. *United States-Canadian Tables of Feed Composition*. 1982. 3rd. rev. ed., Natl. Acad. Press, Washington, DC.

#### ACKNOWLEDGMENTS

This research was supported in part by the Cornell University Agricultural Experimental Station federal formula funds, Project No. NYC-127448, received from the Cooperative State Research, Education, U.S. Department of Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture. We are grateful to Babcock Breeders, Inc., Ithaca, NY, for their generous financial support.

Also, the authors acknowledge the technical assistance of Christine Coupe and the administrative contributions of Barbara Smagner in the preparation of this manuscript.