

Evaluation of different non-fasting molting methods on laying performance and egg quality during molting and post molting periods

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Abstract

The study evaluated different molt-inducing methods to achieve the main goal of molting in commercial layers during molting and post-molting periods. A total of 400 60-week-old Lohmann Brown layers were randomly divided into five groups (eight replicates of 10 birds for each group). Laying hens in the fasting control group received no diet from day 1 to day 10. The second group received a molt-inducing diet recommended by the breeding company. The third group received a wheat bran-based diet. The fourth group received a commercial layer diet with 8,000 ppm zinc (as zinc oxide, ZnO). The fifth group received an induced molting diet given to the second group with 8,000 ppm zinc, respectively. Egg production in the fasting control group and groups fed a diet with ZnO were significantly lower ($p < 0.001$) than those in groups fed the molt-inducing and wheat bran-based diets without ZnO during molting. Egg laying in the fasting control group was rapidly reduced and stopped on the 5.9th day of molting. In both groups having molt treatment with ZnO, egg production was similarly reduced and ceased on the 6.9th day and 7.0th day of molting, respectively, none of them differed significantly from the control. Layers fed molt-inducing diet or wheat bran-based diet did not reach the cessation of laying even on the 28th d of molting period. Relative weights of the ovary and growing oocytes of layers subjected to fasting or fed diets with ZnO were significantly lower than those of other groups. During the first two weeks of post molting, layers fed molt-inducing diet with ZnO showed higher egg production than the other two groups ($p < 0.01$). The eggshell strength in the group fed the commercial diet with ZnO was significantly higher than those fed the molt-inducing diet or wheat bran-based diets at 6 weeks of post molting ($p < 0.05$). These results suggest that the non-feed withdrawal molting using ZnO is more effective in inducing molting and increasing post-molt egg production and egg quality than other methods using a molt-inducing diet alone or wheat bran-based diet without ZnO.

Keywords: Non-fasting molting, Zinc oxide, Egg production, Egg quality, Laying hens

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Availability of data and material

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Authors' contributions

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Ethics approval and consent to participate

The experimental protocol was approved by the Institutional Animal Care and Use Committee at Konkuk University (KU20169).

INTRODUCTION

Induced molting has been practiced by commercial farms in many countries to recover egg production of aged laying flocks for a long time. Successful molting can also prevent age-related decline in eggshell quality [1]. The conventional feed and water withdrawal procedure has been generally used for laying flocks because it is simple and practicable [2] with a satisfactory post-molting laying performance [3]. However, feed deprivation causes severe stress on the body followed by a decrease in immunity and an increase in mortality. It also makes laying flocks more susceptible to *Salmonella* infection [4]. Thus, forced molting by temporary feed and water withdrawal has become a concern to the layer industry due to animal welfare and food safety issues.

An ideal molting method should proceed in a way that protects animal welfare and health without fasting or causing too much stress [2]. European Union (EU) and many other countries have adopted non-fasting molting methods due to the incompatibility between animal welfare and fasting. Likewise, in the Republic of Korea, forced molting based on fasting may soon become a restriction in accordance with the Animal welfare comprehensive plan. Many studies have compared conventional fasting to other non-fasting procedures, including low nutrients diet deficient in protein, calcium, and sodium [5,6], high zinc diet [7,8], and feeding high levels of wheat middling [9] or alfalfa [10]. However, non-fasting procedures have not always been proven to be consistent in ceasing egg production except for a high zinc diet [4]. Feeding a high zinc diet is one alternative to non-fasting molting. It causes less severe stress and provides satisfactory results [8,11]. The objective of this study was to evaluate the effects of four different non-fasting molting methods on the time required to stop and return to egg production and egg quality during molting and post-molting periods.

MATERIALS AND METHODS

The experimental protocol was approved by the Institutional Animal Care and Use Committee at Konkuk University (KU20169).

Animals, diets, and management

A total of 400 60-week-old Lohmann Lite layers were used in this study. Prior to experiments, layers had an acclimation period of two weeks. Layers were randomly allotted to the following five dietary treatment groups (eight replicates of 10 for each group) so that egg production was similar for each group: 1) fasting group, layers received no diet from day 1 to day 10 as control; 2) group 2 layers received the molt-inducing diet recommended by the breeding company (MD); 3) group 3 layers received a wheat bran-based diet as a group with low levels of energy, crude protein (CP), amino acids (AA), and Ca (WB); 4) group 4 layers received a commercial layer diet with 8,000 ppm zinc (CZn); and 5) group 5 layers received the molt-inducing diet with 8,000 ppm zinc (MZn). The zinc was provided in the form of zinc oxide (800 g Zn/kg ZnO).

The formula and chemical compositions of experimental diets are shown in Table 1. Experimental diets and water were provided for *ad libitum* consumption except for the control group during the molting period. At the start of experiment, eight birds from each group were selected, weighed individually, and marked on their legs. A room temperature of $25 \pm 3^\circ\text{C}$ and a natural photoperiod of 14 h of light were maintained throughout the entire experimental period. Proximal compositions of formulated diets are shown in Table 1. Analyzed values of zinc were slightly higher than calculated values.

Table 1. Formula and chemical composition of experimental diets for molt induction

Items	MD	WB	CZn	MZn
Ingredient (%)	100.0	100.0	100.0	100.0
Corn	54.00	17.74	58.96	53.44
Wheat bran	38.98	70.00		38.59
Soybean meal (45%)		2.70	8.80	
Rapeseed meal		2.10	6.80	
Corn gluten meal		0.58	1.95	
DDGS		2.99	9.67	
Tallow	1.00	0.30	1.00	1.00
L-Lysine-HCl (25%)	0.90	0.14	0.47	0.90
DL-Methionine (99%)		0.01	0.05	
Monocalcium phosphate	0.20	0.17	0.57	0.20
Limestone	4.62	3.10	10.18	4.57
Salt		0.07	0.25	
Vitamin premix ¹	0.15	0.03	0.10	0.15
Mineral premix ¹	0.15	0.05	0.15	0.15
Phytase		0.02	0.05	
ZnO	-	-	1.00	1.00
Calculated values ²				
CP (%)	9.75	14.90	15.20	9.55
Ether extract (%)	3.86	3.76	3.96	4.02
Crude fiber (%)	4.82	6.71	3.56	4.67
Crude ash (%)	7.01	7.14	12.95	7.24
Ca (%)	1.80	1.40	4.10	1.68
P (%)	0.59	0.80	0.50	0.58
Available P (%)	0.20	0.20	0.21	0.20
Available Lys (%)	0.30	0.54	0.64	0.30
Available Met (%)	0.15	0.22	0.30	0.15
Available TSAA (%)	0.33	0.47	0.54	0.33
Zinc (mg/kg)	-	-	8,000	8,000
MEn (kcal/kg)	2,520	2,085	2,650	2,500
Chemical composition, analyzed				
DM (%)	88.00	88.57	89.67	88.41
CP (%)	10.07	14.57	15.93	9.79
Ether extract (%)	3.50	3.25	3.73	3.38
Crude fiber (%)	4.73	5.48	3.94	4.27
Crude ash (%)	6.65	7.46	14.41	7.72
Ca (%)	1.79	1.84	4.23	1.83
Total phosphorus (%)	1.79	0.75	0.59	0.57
Zn (mg/kg)	-	-	8.573	8.417

¹Vitamin and mineral mixtures provided the following nutrients per kg of diet: vitamin A, 40,000 IU; vitamin D₃, 8,000 IU; vitamin E, 10 IU; vitamin K₃, 4 mg; vitamin B₁, 4 mg; vitamin B₂, 12 mg; vitamin B₆, 6 mg; vitamin B₁₂, 0.02 mg; pantothenic acid, 20 mg; folic acid, 2 mg; nicotinic acid, 60 mg; Mn, 25 mg; Zn, 50 mg; Fe, 60 mg; Cu, 10 mg; Co, 0.15 mg; Se, 0.10 mg.

²Calculated values are based on raw materials.

MD, group received induced molting diet; WB, group received wheat bran based diet; CZn, group fed commercial layer diet with 8,000 ppm zinc; MZn, group fed induced molting diet with 8,000 ppm zinc; DDGS, distiller's dried grains with soluble; ZnO, zinc oxide; CP, crude protein; P, phosphorus; Lys, lysine; Met, methionine; TSAA, the total sulfur amino acids; MEn, nitrogen corrected metabolizable energy; DM, dry matter.

Changes in body weight, feed intake, and egg production during molting experiment

Diets were freshly added every day and feed intake was recorded weekly by replicate. Eggs were collected at a fixed time every day. The number and weight of eggs laid were recorded during the molting period. Abnormal eggs were excluded from egg weight measurement. Egg mass was calculated as hen-day egg production multiplied by the average egg weight.

The number of days to the cessation of laying of each treatment of layers was also recorded. When egg production reached 0% and body weight (BW) loss reached 20% or more, molting was terminated. The molted layers were fed the commercial diet immediately. The molting experiment lasted up to 28 d. Even if the molting conditions were not met, layers were fed the commercial diet after 28 d of molting period.

Changes in the ovary and growing oocytes

At the end of the molting experiment, one bird per replicate was sacrificed by CO₂ asphyxiation. Its ovary and growing oocytes samples were carefully removed and weighed. Relative weights of these samples were expressed as a percentage of live BW.

Changes in egg production and egg quality during the post-molting experiment

During the post-molting period, individual BWs of eight hens from each group were monitored at the start and the end of the experiment. All birds were fed the commercial layer diet containing 15% of CP and 2,700 kcal/kg of nitrogen corrected apparent metabolizable energy (AMEn) during the post-molting experiment. The diet and water were provided for *ad libitum* consumption. Diets were freshly added every day and feed intake was recorded weekly by replicate. Eggs were collected at a fixed time every day. The number and weight of eggs laid were recorded during the post-molting period. Abnormal eggs were excluded for egg weight measurement. Egg mass was calculated as hen-day egg production multiplied by average egg weight. Numbers of days to start laying, days to return to 50% egg production, and days to return to pre-molting egg production were also recorded.

Egg quality was determined bi-weekly during the post-molting experiment. Five eggs from each replicate were collected, weighed, and stored overnight at room temperature (20 °C) for subsequent analyses. The breaking strength of sampled eggs was measured using a DET-6000 digital egg tester (Nabel, Kyoto, Japan). Eggshell thickness without shell membrane was measured using a micrometer (series 547-360 Digimatic micrometer, Mitutoyo, Japan). Egg yolk color was determined by comparison with Roche yolk color fan (Hoffman-La Roche, Basel, Switzerland). Albumen height was also measured using the DET-6000 digital egg tester (Nabel). Haugh unit calculation was then performed.

Statistical analysis

Data were analyzed by the GLM procedure of SAS [12] with cage lot (two adjacent cages) as experimental units for evaluating egg production and egg quality and individual birds as the unit for other criteria. Significant differences were determined using Duncan's multiple range test at $p < 0.05$.

RESULTS AND DISCUSSION

Egg production, body weight, and feed intake during molting experiment

The productivity and BW of layers before and during molting experiment are shown in Table 2. Before molting, the average egg production exceeded 80%, showing no significant difference among

Table 2. The mean body weight, feed intake and egg production of laying hens subjected to various molting methods before and after molt induction¹⁾

	Control	MD	WB	CZn	MZn	Pooled SEM	p-value
Egg production							
Before molt induction (%)	84.2	82.3	81.5	82.3	82.3	2.675	0.963
During 7 d of molt (%)	31.6 ^c	70.7 ^a	73.3 ^a	40.9 ^b	36.9 ^{bc}	2.750	< 0.001
Egg weight							
During 7 d of molt (g/egg)	39.7 ^d	59.8 ^{ab}	61.0 ^a	53.1 ^{bc}	50.6 ^c	2.480	< 0.001
Day to cessation of laying (d)	5.9	-	-	6.9	7.0	0.342	0.060
Mean BW							
Before molt induction (g/bird)	1,937	1,919	1,962	1,913	1,948	26.291	0.666
After molt (g/bird)	1,483 ^c	1,593 ^b	1,704 ^a	1,546 ^{bc}	1,537 ^{bc}	31.257	< 0.001
Weight loss (%)	23.5 ^a	16.6 ^{bc}	13.1 ^c	19.2 ^{ab}	21.1 ^{ab}	1.443	< 0.001
Feed intake during 10 d of molt (g/d/bird)	-	84.2 ^a	90.3 ^a	21.8 ^b	18.4 ^b	3.073	< 0.001
Weight of ovary after molting (g/100 g BW)	0.58 ^b	2.19 ^a	2.20 ^a	0.86 ^b	0.72 ^b	0.104	< 0.001

¹⁾Data are least square of mean of eight replicates with two cages (five birds per cage).

^{a-d)}Mean values with different superscripts within the same row differ significantly ($p < 0.05$).

Control, fasting group; MD, group received induced molting diet; WB, group received wheat bran based diet; CZn, group fed commercial layer diet with 8,000 ppm zinc; MZn, group fed induced molting diet with 8,000 ppm zinc; BW, body weight.

groups. Mean egg production in fasting control and groups fed diets with ZnO were significantly lower ($p < 0.001$) than those of MD and WB during 7 d of molting. Egg production in the latter two groups were reduced by 10 % or slightly more than those before molting. The mean egg weight was the lowest in the fasting control group but the highest in the WB group during 7 d of molting. Egg weights in groups fed diets with ZnO were significantly lower than that of the WB group, but higher than that of the fasting control group ($p < 0.001$).

Egg production in fasting control was rapidly reduced. It ceased at 5.9 d of molting. In both molt treatment with ZnO, egg production was similarly reduced and ceased after 6.9 d and 7.0 d of molting period, respectively, none of which differed significantly from that of the control. After egg production had stopped, layers kept fasting or fed diets with ZnO to obtain the weight loss goal until 10 d of the experiment. Layers fed MD and WB did not reach cessation of laying even on the 28 d of molting period. Therefore, it was judged that molting was incomplete in these two groups fed diets without ZnO.

Conventional feed withdrawal procedure seems to be the fastest way to stop egg laying, even if it goes against animal welfare. When feed deprivation is used in a molting procedure, egg laying is stopped on 6 d [13]. Machebe et al. [8] have reported that layers fed diets with high levels of zinc (5,000 to 20,000 ppm as ZnO) show rapid reduction in egg production and cease laying within 9 d of molting experiment. Similarly, layers fed diets with varying levels of ZnO show dramatic reduction in egg production and stop laying within 6.8 d of experiment in a linear manner [14]. On the other hand, diets with low levels of CP or nutrients and WB have not always been proven to be consistent in ceasing egg production [4]. Hwangbo et al. [9] have found that layers fed diet containing 90% or 70% wheat bran show reduced egg production of 31.0% or 28.4%, respectively, and that laying does not stop completely until the end of a 4-wk experiment. When layers are fed a low CP diet, egg production slows down and stops after 4 weeks of feeding [5]. In the present study, layers fed a MD with low nutrients and a WB did not reach the cessation of laying even on the 28 d of molting period. Both groups (MD and WB) did not reach the expected molting index either.

Average feed intake of CZn and MZn were significantly lower than those of MD and WB

during 10 d of molting ($p < 0.001$). There were significant differences in BW and weight loss % among groups at different molting periods (10th d for control group and groups fed diets with ZnO; 28th d for groups fed diets without ZnO). Layers in the fasting group had the highest weight loss, followed by MZn and CZn at 10th d of molting period. Weight loss % in MD and WB groups were relatively low (-16.6 and -13.1, respectively)

Weight loss is directly associated with a decrease in feed intake. Layers fed diets with ZnO had lower feed intake (21.8 g, and 18.4 g/hen per day) than did layers fed MD and WB. The decreased feed intake could be due to low palatability of high levels of zinc [15] or ability of zinc cation to induce follicular atresia [7]. In this study, observations of BW and weight loss regardless of molting period (10th d or 28th d) were in agreements with previous studies. Laying hens that are subjected to conventional feed withdrawal lose 20% of BW on 5 d of experiment [16]. In contrast, BW loss % in MD and WB groups did not reach the weight loss goal even on the 28 d of molting period. The BW loss of layers subjected to fasting and fed diets with ZnO were within the ranges suggested by Baker et al. [17] for proper post-molting performance. Layers fed diets with ZnO had greater BW loss (at an average of 20.2% from initial BW) at the end of 10 d molting period than any other non-fasting treatments even on the 28 d.

Relative weights of ovary and growing oocytes

Relative weights of ovary and growing oocytes in layers subjected to fasting and fed diets with ZnO were significantly lower than those of MD and WB groups at 10th d or 28th d of molting period each ($p < 0.001$). Layers subjected to conventional fasting had the lowest relative weight, followed by CZn and MZn, none of which differed significantly (Table 2).

The regression of ovary is directly related to the rejuvenation process [4]. Weight loss of ovary and growing oocytes occurred simultaneously with BW loss in this study. There was no significant difference in relative ovary weight among fasting control and groups fed diets with ZnO. These observations are consistent with a previous report [18]. It has been suggested that high levels of dietary zinc can induce follicular atresia, which can lead to subsequent cessation of egg production by interfering with the process of ovulation in laying hens [19].

Egg production and egg quality during post-molting experiment

Egg production, the number of days to start laying, days to return to 50% egg production, and days to return to pre-molting egg production in three groups with complete molting are shown in Table 3. During the first 2 wks of post-molting, MZn showed higher egg production than those in the other two groups ($p < 0.01$). Egg weight and daily egg mass in the MZn group were significantly higher than those of fasting control ($p < 0.05$). There was no significant difference in feed intake among three groups during this period. Days to start laying in two groups fed diets with ZnO were significantly reduced than that in the group subjected to fasting (7.9 d and 7.8 d vs. 9.5 d) ($p < 0.05$). There was no significant difference in days to return to 50% egg production or return to pre-molting levels among groups.

At the start of the post-molting experiment, the BW was the lowest in the fasting control group ($p < 0.01$). However, layers recovered the BW loss after 6 wks of feeding. The weight gain % ranged from 16.9 for WB group to 33.1 for fasting control ($p < 0.001$). From 3 to 6 wk of post-molting period, egg production in control group and groups fed diets with ZnO were numerically higher but not significantly higher than those of incomplete molting groups. Egg weight in the control group was significantly higher than the group fed MD without ZnO ($p < 0.05$). There was no significant difference in daily egg mass or feed intake among groups during this period (Table 4).

There was no significant difference in eggshell strength among groups at 2 wk of post-molting

Table 3. The egg production of laying hens subjected to various molting methods during first two weeks after molting (three groups with complete molting)¹⁾

	Control	CZn	MZn	Pooled SEM	p-value
Egg production (%)					
During 2 wk of post molting	21.5 ^b	20.8 ^b	28.3 ^a	1.610	0.006
Egg weight (g/egg)					
During 2 wk of post molting	22.5 ^b	24.8 ^{ab}	29.4 ^a	1.793	0.039
Daily egg mass					
During 2 wk of post molting	4.9 ^b	5.1 ^b	8.4 ^a	0.578	0.001
Feed intake (g/bird/d)	116.5	115.6	116.4	1.212	0.851
Day to start of laying (d)	9.5 ^a	7.9 ^b	7.8 ^b	0.452	0.021
Day to return to 50% egg production (d)	11.6	12.4	10.8	0.445	0.055
Day to return to pre-molting levels (d)	14.8	15.0	14.8	0.991	0.979

¹⁾Data are least square of mean of eight replicates with two cages (five birds per cage).

^{a,b}Mean values with different superscripts within the same row differ significantly ($p < 0.05$).

Control, fasting group; CZn, group fed commercial layer diet with 8,000 ppm zinc; MZn, group fed induced molting diet with 8,000 ppm zinc.

Table 4. The egg production, feed intake and body weight of laying hens subjected to various molting methods during three to six weeks of post-molting¹⁾

	Control	MD	WB	CZn	MZn	Pooled SEM	p-value
Mean BW							
Before refeeding (g/bird)	1,348 ^e	1,430 ^{bc}	1,533 ^a	1,421 ^{bc}	1,452 ^{ab}	29.206	0.003
After 6 wk of post molting (g/bird)	2,017 ^a	1,794 ^d	1,846 ^{cd}	1,907 ^{bc}	1,952 ^{ab}	33.467	< 0.001
Weight gain (%)	33.1 ^a	20.7 ^c	16.9 ^d	25.4 ^b	25.6 ^b	1.244	< 0.001
Egg production (%)							
During 3–6 wk of post molting	88.7	84.4	81.2	90.2	88.8	2.516	0.158
Egg weight (g/egg)							
During 3–6 wk of post molting	66.5 ^a	62.8 ^b	64.5 ^{ab}	64.2 ^{ab}	64.0 ^{ab}	0.749	0.032
Daily egg mass							
During 3–6 wk of post molting	58.9	53.5	53.2	57.8	55.6	1.711	0.106
Feed intake for post molting (g/d/bird)	117.6	111.7	111.2	115.2	115.0	1.694	0.065

¹⁾Data are least square of mean of eight replicates with two cages (five birds per cage).

^{a-d}Mean values with different superscripts within the same row differ significantly ($p < 0.05$).

Control, fasting group; MD, group received induced molting diet; WB, group received wheat bran based diet; CZn, group fed commercial layer diet with 8,000 ppm zinc; MZn, group fed induced molting diet with 8,000 ppm zinc.

period (Table 5). The eggshell strength in the CZn group was significantly higher than those of incomplete molting groups at 6 wk of post-molting period ($p < 0.05$). The Haugh unit was the highest in the fasting control group than in other groups at 2 wk of post-molting period ($p < 0.01$), although it was not significantly different at 4 wk or 6 wk of post-molting period. Yolk color values in the control group and groups fed diets with ZnO were significantly higher than those of incomplete molting groups at 4 wk of post-molting period ($p < 0.001$).

It was shown that 0% egg production could not be obtained by MD or WB group in this study. Thus, these two groups were excluded from the recovery of egg production. The MZn group showed higher egg production and egg weight than those of the fasting control group during the first 2 wks of recovery ($p < 0.05$). Days to start of laying were about 1 d earlier in groups fed diets with ZnO, although there were no significant differences in days to return to egg production or to pre-molting levels among the three treatments (Table 3). Similarly, Goodman et al. [20] have found

Table 5. The egg and eggshell qualities of laying hens subjected to various molting methods during post molting¹⁾

	Control	MD	WB	CZn	MZn	Pooled SEM	p-value
Eggshell strength (kg/cm ²)							
2 wk post molting	4.72	4.79	4.63	4.79	4.9	0.186	0.888
4 wk post molting	5.05	4.53	4.68	5.08	4.94	0.150	0.059
6 wk post molting	4.77 ^{ab}	4.54 ^b	4.53 ^b	5.16 ^a	4.75 ^{ab}	0.149	0.045
Eggshell thickness (mm)							
2 wk post molting	0.41	0.43	0.43	0.42	0.42	0.006	0.061
4 wk post molting	0.43	0.42	0.43	0.43	0.44	0.005	0.505
6 wk post molting	0.41	0.43	0.43	0.43	0.43	0.005	0.053
Haugh unit							
2 wk post molting	84.5 ^a	80.1 ^b	78.1 ^b	80.6 ^b	80.3 ^b	1.064	0.004
4 wk post molting	80.0	78.4	78.2	77.0	76.3	1.007	0.119
6 wk post molting	81.2	81.1	80.7	82	81.3	0.862	0.829
Yolk color							
2 wk post molting	8.8	8.8	8.6	8.6	8.6	0.084	0.251
4 wk post molting	8.6 ^a	8.3 ^b	8.3 ^b	8.8 ^a	8.6 ^a	0.067	< 0.001
6 wk post molting	8.5	8.4	8.5	8.6	8.5	0.073	0.082

¹⁾Data are least square of mean of eight replicates with two cages (five birds per cage).

^{a,b}Mean values with different superscripts within the same row differ significantly ($p < 0.05$).

Control, fasting group; MD, group received induced molting diet; WB, group received wheat bran based diet; CZn, group fed commercial layer diet with 8,000 ppm zinc; MZn, group fed induced molting diet with 8,000 ppm zinc.

no significant differences in days to return to 50% egg production or subsequent laying performance during 22 wks of experiment.

From 3 to 6 wks of post-molting period, egg production in the control group and groups fed diets with ZnO were numerically but not significantly higher compared with those of incomplete molting groups (Table 4). During this period, egg production and egg weight results were shown to be similar between layers subjected to fasting and layers fed diets with ZnO during the post-molting period. As previously reported, egg production of layers fed diets with ZnO as well than layers molted by fasting performed during post-molting period [1]. With similar methods of molting, Onbařilar and Erol [3] have also found no difference in egg production between conventional fasting and a zinc-based diet. It has been suggested that properly induced molting is an effective way to improve eggshell quality in aged laying flocks [4,21]. The eggshell strength was higher in the CZn group than those of incomplete molting groups at 6 wk of post-molting period ($p < 0.05$). Difference in eggshell strength tended to lack significance between the group subjected to fasting and groups fed diets with ZnO. These results were consistent with results of Karimi et al. [13] that showed no significant difference in eggshell quality between post-molt eggs from layers molted by fasting and those by a high zinc diet. Based on egg production and egg quality, molting diets with ZnO are similarly effective in inducing molting and increasing post-molt performance than the conventional fasting method.

The present study provides available information on the time required to stop and return to egg production by application of non-feed withdrawal molting during molting and post-molting periods. Results of this study indicate that a non-feed withdrawal molting using ZnO can be used in the industry with success. In addition, these molting diets do not seem to disturb the normal physiology of layers based on performance indices. It is considered that more than 5,000 ppm of zinc is required for satisfactory molting [20]. But the use of zinc in feed should be strictly regulated due to the environmental emission of zinc. Further studies are needed to clarify the minimum levels

of dietary zinc while effective for non-feed withdrawal molting.

REFERENCES

1. Silva-Mendonça MCA, Fagundes NS, Mendonça GA, Gonçalves FC, Fonseca BB, Mundim AV, et al. Comparison of moulting methods for layers: high-zinc diet versus fasting. *Br Poult Sci.* 2015;56:598-604. <https://doi.org/10.1080/00071668.2015.1084412>
2. Koelkebeck KW, Anderson KE. Molting layers—alternative methods and their effectiveness. *Poult Sci.* 2007;86:1260-4. <https://doi.org/10.1093/ps/86.6.1260>
3. Onbaşılar EE, Erol H. Effects of different forced molting methods on postmolt production, corticosterone level, and immune response to sheep red blood cells in laying hens. *J Appl Poult Res.* 2007;16:529-36. <https://doi.org/10.3382/japr.2006-00089>
4. Berry WD. The physiology of induced molting. *Poult Sci.* 2003;82:971-80. <https://doi.org/10.1093/ps/82.6.971>
5. Hong EC, Park HD, Na SH, Kim HK, Yu DJ, Park MN, et al. Effect of the induced molting with low-protein and energy diet on the postmolt performance and egg quality of layers. *Korean J Poult Sci.* 2010;37:117-23. <https://doi.org/10.5536/KJPS.2010.37.2.117>
6. Naber EC, Latshaw JD, Marsh GA. Effectiveness of low sodium diets for recycling of egg production type hens. *Poult Sci.* 1984;63:2419-29. <https://doi.org/10.3382/ps.0632419>
7. Johnson AL, Brake J. Zinc-induced molt: evidence for a direct inhibitory effect on granulosa cell steroidogenesis. *Poult Sci.* 1992;71:161-7. <https://doi.org/10.3382/ps.0710161>
8. Machebe NS, Iweh P, Onyimonyi AE, Ekere OS, Abonyi F. Zinc oxide as an effective mineral for induced moulting: effects on post moulting performance of laying hens in the humid tropics. *J Vet Sci Technol.* 2013;S11:003. <https://doi.org/10.4172/2157-7579.S11-003>
9. Hwangbo J, Hong EC, Kang BS, Kim HK, Heo KN, Choo HJ, et al. Effect of the induced molting with wheat bran on the postmolt performance of laying hens. *Korean J Poult Sci.* 2011;38:205-11. <https://doi.org/10.5536/KJPS.2011.38.3.205>
10. Donalson LM, Kim WK, Woodward CL, Herrera P, Kubena LF, Nisbet DJ, et al. Utilizing different ratios of alfalfa and layer ration for molt induction and performance in commercial laying hens. *Poult Sci.* 2005;84:362-9. <https://doi.org/10.1093/ps/84.3.362>
11. Fard MK, Ghasemi R, Dirandeh E, Torki M, Rezaei M. Effect of zinc oxide, potassium iodide and withdrawal diet as alternative moulting methods on performance of commercial laying hens. *J Appl Anim Res.* 2020;48:534-42. <https://doi.org/10.1080/09712119.2020.1837840>
12. SAS. SAS/STAT user's guide. Version 8. Cary, NC: SAS Institute; 2002.
13. Karimi S, Khajali F, Rahmani HR. Chemical and non-chemical molting methods as alternatives to continuous feed withdrawal in laying hens. *J Agric Sci Technol.* 2009;11:423-9.
14. Al-Kirkuki SMS, Ali KA. Effect of force molting by zinc oxide and the role of vitamin C on body weight and reentry to production of broiler breeder. *Mesop J Agric.* 2012;40:9-18. <https://doi.org/10.33899/magrj.2012.63472>
15. Fox MRS. Zinc excess. In: Mills CF, editor. *Zinc in human biology*. London: Springer-Verlag Berlin Heidelberg; 1989. p. 365-70.
16. Hassanabadi A, Kermanshahi H. Effect of force molting on postmolt performance of laying hens. *Int J Poult Sci.* 2007;6:630-3. <https://doi.org/10.3923/ijps.2007.630.633>
17. Baker M, Brake J, McDaniel GR. The relationship between body weight loss during an induced molt and postmolt egg production, egg weight, and shell quality in caged layers. *Poult Sci.* 1983;62:409-13. <https://doi.org/10.3382/ps.0620409>
18. Berry WD, Brake J. Comparison of parameters associated with molt induced by fasting, zinc,

- and low dietary sodium in caged layers. *Poult Sci.* 1985;64:2027-36. <https://doi.org/10.3382/ps.0642027>
19. Khan RU, Nikousefat Z, Javdani M, Tufarelli V, Laudadio V. Zinc-induced moulting: production and physiology. *Worlds Poult Sci J.* 2011;67:497-506. <https://doi.org/10.1017/S0043933911000547>
 20. Goodman BL, Norton RA Jr, Diambra OH. Zinc oxide to induce molt in layers. *Poult Sci.* 1986;65:2008-14. <https://doi.org/10.3382/ps.0652008>
 21. Akbari Moghaddam Kakhki R, Mousavi Z, Anderson KE. An appraisal of moulting on post-moult egg production and egg weight distribution in white layer hens; meta-analysis. *Br Poult Sci.* 2018;59:278-85. <https://doi.org/10.1080/00071668.2018.1432032>