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Original Research

Comparing the Efficacy of Feed Withdrawal and Corn Diet Systems for Induced Molting on Health and Performance of Broiler Breeder Flocks

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Abstract

This study was conducted to compare the effectiveness of two induced molting methods (The modified California method and the reduced nutrient method) and to determine the preferable method that achieves the main goals of post-molt in breeder hens. Twenty-four commercial Ross broiler breeder flocks (59 weeks old) were used. The birds were divided into two groups (12 flocks each). Group 1 (G1) was subjected to a modified California forced molting method, while Group 2 (G2) was subjected to a reduced-nutrient method (low-protein low-energy diet). Body weight (BW), weight loss, mortality, and egg production cease were determined before the molting period, while feed intake (FI), body weight gain (BWG), mortality, egg production, fertility, and hatchability% were recorded after molting. The results of this study indicated that, although the California treatment ceased egg production earlier than the reduced nutrient molting method (day 8 and day 14) respectively, and the weight loss achieved after 28 d in the California method (28.7%) versus (30.4% after 36 days) in the reduced-nutrient system. The reduced nutrient system showed a lower mortality rate and a higher BW at the start and the end of the molting period. Additionally, the reduced nutrient system showed enhanced post-molt performance, as demonstrated by improved BWG, lower mortality%, higher egg production% (79.1%) versus (74.5%) in the California group, and better hatchability%. The FI and fertility% not significantly affected between the different groups. In conclusion, forced molting by the reduced-nutrient method achieved the main goals of induced molting and recorded the best values in productive traits in the post-molt period. So, it can be used as a viable alternative to the feed withdrawal method for the successful induction of molting from both the economic and welfare points of view.

KEYWORDS
Fasting, Low-protein low-energy, Body weight loss, Molt ration, Hatchability, Welfare.

INTRODUCTION

The poultry industry is at the forefront of animal production due to the technological advancement and significant revenues (Sgavioli *et al*., 2013). In the commercial egg industry, forced molting is a common management tool, inducted after the first year of the egg production cycle to extend hens' egg production for a second cycle by rejuvenating their reproductive organs (Anwar *et al*., 2015; Iftikhar *et al*., 2015). Forced molting enhances egg quality parameters (e.g., egg albumin and shell quality), fertility, and hatchability that deteriorate after 1-year of production (Keshavarz and Quimby, 2002; Sh and Taboosha, 2017; Anwar *et al*., 2015; UEP, 2016; Akbari Moghaddam Kakhki *et al*., 2018). Also, it has a vital role in decreasing the replacement flocks' costs (Bell, 2003) and improves the feed conversion rates and post-molting performance (Faitarone *et al*., 2008).

The choice to adopt a forced molting program is influenced by several criteria, including the cost of a replacement new flock, egg quality, egg price, feed cost, maximum facility utilization, and the molting method used (Reddy *et al*., 2008). Recently, many force molting techniques have been used, such as feed withdrawal with or without water/light restriction, (Berry, 2003; Park *et al*., 2004b), provision of low-nutrient rations to birds deficient in protein, energy, calcium, or sodium levels (Petek, 2001; Keshavarz and Quimby, 2002), dietary supplementation of certain minerals such as high zinc, aluminum or iodine levels (Park *et al*., 2004a), use of food waste material like wheat middling's (Koch *et al*., 2007), cottonseed meals (Davis *et al*., 2002), jojoba meal (Koelkebeck and Anderson, 2007), alfalfa (Mcreynolds *et al*., 2006; Aygun and Olgun, 2010), a whole-grain barley diet (Onbasilar and Erol, 2007) or oat (Tona *et al*., 2002; Aygün and Yetisir, 2009), and hormonal treatment including progesterone, prolactin and chlormadinone (Khan *et al*., 2013).

The poultry producers commonly practiced molt induction by feed withdrawal for several days up to 30% body weight reduction (BWR) due to its easy application, cost-effectiveness, management friendly, and enhanced post-molt performance (Koelkebeck *et al*., 2006; Souza *et al*., 2010). Feed withdrawal causes weight reduction, which is crucial for the renewal and rest of reproductive organs (Khoshoei and Khajali, 2006). After molting, the eggs produced for incubation had much superior weight results compared to the eggs produced in a continuous process (Oguike *et al*., 2004). Also, eggs with a better shell and interior quality are produced at a higher rate than before they had molted (Webster, 2003). From the perspectives of both animal welfare and food safety issues, the induction of molting by temporary

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feed withdrawal has recently become the target of severe criticism (Soe *et al*., 2007).

Also, the increased public awareness of the animal stress caused by feed withdrawal has prompted researchers to study alternate molting strategies (Aygun, 2013). Alternative methods without total feed withdrawal using partial feed restriction called non-feed withdrawal techniques, are highly desirable (Park *et al*., 2004b). Non-feed-withdrawal approaches may be beneficial in terms of post-molt egg production performance (Biggs *et al*., 2003). Additionally, may result in appropriate technical and ecological outcomes, simple to implement and take animal welfare into account (Sarıözkan *et al*., 2013).

Accordingly, the goal of this study was to compare two induced molting strategies: The modified California method and the reduced nutrient method (low-protein and low-energy diet), to examine if the non-feed-withdrawal technique can be employed to induce molting with equal effectiveness as the widely used feed withdrawal program. Additionally, the study aimed to determine which approach is better for achieving key post-molt goals of the breeder hens.

MATERIALS AND METHODS

Ethical statement

The experimental procedures applied in this experiment were approved by the Institutional Animal Care and Use Committee, Faculty of Veterinary Medicine, Cairo University, Giza, Egypt (Vet CU 20092022466).

Broiler breeder flocks and housing

The study included twenty-four commercial Ross broiler breeder flocks (59 weeks of age), which were raised in closed floor houses with a fully controlled environment and temperature (24-25°C). Houses were bedded with wood shaving of 7-8 cm depth. Stocking densities were 40,000 birds/flock, with a 9% male-to-female ratio that gradually declined to 6.8% at the time of molt (60 weeks of age). Birds were equally allotted into two groups (12 flocks/group). Group 1 (G1) was subjected to a modified California forced molting system, while group 2 (G2) was subjected to reduced-nutrient rations deficient in protein and energy.

Before inducing molting, birds received 15 hours of photoperiod from 4 am to 7 pm + 9 hours of darkness and 60-70 Lux lighting intensity. The breeders were fed on a Breeder-2 ration according to the recommended requirements of the Ross breeding guide (Table 1) (Aviagen, 2018). Daily FI per bird was 152-159 grams at 59 weeks of age (provided for 3-4h/day), and water was available all the time through suspended lines of fast-flow nipples (one nipple/8 birds). At 59 weeks of age (before molting), the total egg production was 67%, and the average egg weight was 68±2 grams. Before molting, flocks were examined, where weak and emaciated birds were discarded. A representative sample of 10% of females from each flock was randomly selected and individually weighed to obtain the average BW; just before inducing the molting.

Table 1. Ingredient and composition of diets in different growing periods.

	Starter ration	Grower ration	Pre-laying ration	Production ration (Breeder 1)	Production ration (Breeder 2)	Molting ration 1	Molting ration 2
Corn	566.1	613.15	602.45	664.39	675	498.3	635.35
Soybean meal (48% crude protein)	309.5	257.5	178.5	224.2	211.2	0	150
Gluten	20	0	0	10.7	0	0	40
Soya oil	5	5	5	5	5	0	0
Wheat bran	50.8	75	164.7	0	6.7	493	116
Fine limestone	6.65	6.75	10.5	32.8	35.9		15
Coarse limestone	6.65	6.75	10.5	32.8	35.9		15
Monocalcium phosphate	0	0	0	0	0		0
Dicalcium phosphate	18.3	18.5	13.9	13	13		16
Salt	3	2.6	2.5	2.8	2.8	3	3
Na bicarbonate	1.2	1.8	1.9	1.6	1.6		0.5
Biotin	0.5	0.5	0.5	0.5	0.5		0
Lysine	0.6	2.6	0	0	0		0.65
Methionine	2.2	1.5	1.2	1.8	1.9		0.3
Threonine	0.4	0	0	0.01	0.1		0
Choline	1	1	1	1	1	1	1
Enzyme (Phytase)	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Premix[1]	4	4	4	5	5	4	5
Calculated content (%)							
Crude protein	20.39	17.65	15.09	15.84	14.79	11.13	15.81
Metabolizable energy (kcal/kg)	2792	2798	2697	2818	2795	2360	2780
Calcium	1.06	1.1	1.26	2.87	3.08	0.19	1.66
Av. phosphorus	0.64	0.66	0.65	0.48	0.48	0.72	0.65

[1]Provided per kilogram of diet.

Molting Feeding program

Modified California molting system

For the first four days of the molting regime, the feed amount per bird was reduced to 63% (100 g) of the feed amounts before molting (159 g). From day 5 of the molting program, birds were deprived completely of feed until 14 days (Table 2). After that, birds received 60 g of Molt-2 ration for 7 days, then 90 g for another 7 days. All birds received a mixture of vitamins and amino acids in water 3-times weekly during the molting period. After reduction of BW to 25–30% of the initial weight, until the end of the molting period, birds received a gradual increase from 100g to 120 g Molt-2 diet which was changed at 5% egg production to production ration (125 g), according to the breeder management guide.

Reduced nutrient (corn diet) system

For the first 14 days, the Production-2 diet was administered and daily reduced from 159 g to 50 g/bird. Then, the Molt-1 ration (corn diet) was introduced from day 15 till day 35, with a gradual increase from 50 g to 100 g/bird. After that, 100 g of the Production-1 diet was administered to each bird, which was raised to 125 g/bird at 5% egg production (Table 3).

Light

A gradual reduction of the daily photoperiod was started at the same time of feed withdrawal or reduction as it was 14-15 hours/day for the first days, then decreased to only 8 hours/day (5-8 Lux) until the end of the molting period. Following the molting period, the daily photoperiod was increased gradually following the breeder management guide considering the increase in egg production (Tables 2 and 3).

Average body weight (BW)

During the molting period, birds were previously weighed individually, and their average BW was calculated and recorded. The weighing process was carried out every 4 days during the molting period and weekly, after that BWG was calculated weekly during the post-molting period.

Mortality

The number of dead birds was recorded daily during and after the induced molting period. The mortality percentages were calculated in relation to the initial number of housed birds.

Egg production

Egg production was recorded daily during the molting period and weekly during the post-molting period. The calculation was based on hen housed as follows: Egg production in % = (Number of eggs produced/week/ Number of housed hens) × 100 (El-Deek and Al-Harthi, 2004). Fertility and hatchability percentages were recorded during the post molting period weekly.

Table 2. Modified California forced molting program allowed to broiler breeder hens.

Age/week	Molting period	Feed intake (g/bird)	Ration	Photoperiod (hours/day)	Light intensity (Lux)
Week 59	Day zero	159 g	Production-2	15	60
Week 60	Days 1- 4	100 g	Production-2	14	60
Weeks 60-61	Days 5- 14	Fasting #	No ration	8	5
Week 62	Days 15- 21	60 g ^	Molt-2	12	60
Week 63	Days 22- 28	90 g *	Molt-2	13	60
Week 64	Days 29- 35	100 g ^	Molt-2	13	60
Week 65	Days 36- 42	110 g $	Molt-2	13	60
Weeks 66-67	Days 43- 50	120 g **	Molt-2	14	60
Weeks 68- 69 (At 5% egg production)		125 g +	Production-1	15	60

Multi-vitamins and amino acids supplements in drinking water: Vita-Amino plus® (3g/L); Olivo® (2ml/L); AD3E (3ml/L); Pureformax® calcium supplement (3g/L); E-selenium (2ml/L); Amino acids (3ml/L).
^ Preliminary diet supplemented with Anti-Mycoplasma premix Tylvamyco® (Tylvalosin) (1.5kg/ton), then after 21 days preliminary diet supplemented with Terramycin 40% (1 kg/ton) was added.
* Drinking water was supplemented with Anti-helminths (Levamisole 1ml/ L) for 2 days.
$ Diet supplemented with Anti-helminths Flozol (600g/ton) as anthelminthic.
** Birds vaccinated against NDV, IBD, IB, AI H5 and H9, and EDS.
+ Production diet (Breeder 1)

Table 3. Reduced nutrients diet (corn diet) allowed to broiler breeder hens.

Age/week	Molting period	Feed Intake (g/bird)	Ration	Photoperiod (hours/day)	Light intensity (Lux)
Week 59	Day zero	159	Production-2	15	60
Weeks 60 to 61	Days 1-14	159 g then decrease daily till reach to 50 g	Production-2	8	5
Weeks 62 to 67	Days 15-35	Corn diet (50 g daily increase till reach to 100 g) *	Molt-1	8	5
Weeks 67 to 69	Days 36-68	Full diet 100 g	Production-1	14-15	60
Weeks 69 to 70 (At 5% egg production)		125 g	Production-1	15	60

* Cereals, low-protein and low-energy diet.

Statistical analysis

Data were presented as means ± standard error (SE). An independent sample t-test was applied to compare means between different groups. Statistical analysis was performed using PASW Statistics, version 18.0 (SPSS Inc., Chicago, IL, USA). Significance was determined at P < 0.05. Scatter plots were designed in R (R foundation for statistical computing), version 4.2.2, using the 'ggplot2' package (Wickham, 2016).

RESULTS

During the molting programs

In this study, two molting systems (feed withdrawal vs. corn diet) were applied on 59-week-old Ross-broiler breeder hens. Molting programs started from the 60th week till the 69th week of age. BW of hens before and during the molting period were presented in Table 4 and Figure 1. Results showed that on day zero before molting (pre-molt period), no significant differences (P = 0.941) existed in the live BW between hens of both groups.

On G1, feed reduction for 4 days followed by feed withdrawal (Modified California system) for 10 days caused a significant (P < 0.0001) abrupt decline in BW and substantially accelerated BW loss% when compared with hens maintained on low-nutrient corn diet (G2). The difference in weights between G1 and G2 during the first 15 days of the molting program ranged from 4 to 9% (P < 0.0001), with G1 exhibiting lower BW.

The reduction% in BW in the Modified California system (G1) ranged from 4.1% on day 1 to 21.5% on day 12, while the low-nutrient diet system (G2) ranged from 2% on day 1 to 17.6% on day 12 (P < 0.0001) (Table 4). However, at the end of the day 14 of the molting program, there were no significant difference (P = 0.094) in BW loss% between G1 (24.2%) and G2 (22.8%). Birds on the Modified California system lost 28.7% of their BW after 29 days, while birds on the reduced-nutrient corn diet lost 30.4% of their BW after 36 days from the beginning of molt induction. At the end of the experiment (69 weeks of age), the BW of birds on the low-nutrient diet was significantly higher than the Modified California system (P < 0.05).

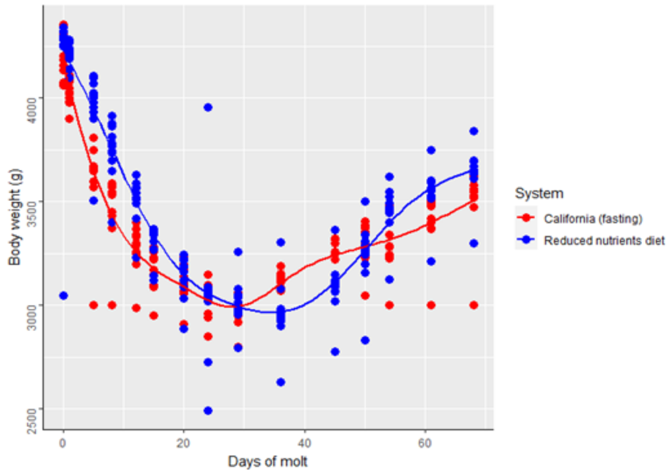

Fig. 1. Differences in body weights of breeder hens over time during forced molting by two systems.

The reduced nutrient corn diet supported a gradual steady decrease in BW (in the first 25 days of molt), reached a prominent peak in BW loss% (day 36 of molt), and achieved a high BW restoration from day 50 to the end of molt (day 68). On the other hand, the California system induced a rapid decline in BW (in the first 14 days of molt), reached a fast peak in BW loss% (day 29 of molt), and showed a relaxed BW restoration curve from day 40 to end of molt (day 68) (Table 4 and Fig. 1).

In the Modified California system, the egg production gradually decreased until stopped after 8 days of feed deprivation, while in the reduced-nutrient system, the egg production stopped after 14 days of reduced diet. Whereas 5% of egg production was restored from 68 to 69 weeks in the Modified California system, and from 69 to 70 weeks in the reduced-nutrient system (Tables 2 and 3).

Figure 2 shows the mortality rates during the molting programs. On the first 20 days of molting, hens subjected to the Modified California system had 0.4 to 0.6% mortality which is

Table 4. Body weights and body weight change % of breeder hens when subjected to different systems of forced molting.

		Means of BW (g) ± SE			Means of BW reduction change % ± SE		
Age (weeks)	Time from molt	Modified California	Low nutrient diet	*P*- value	Modified California	Low nutrient diet	*P*- value
Week 59	Before molt	4201±29	4193±104	0.941	-	-	-
Week 60	Day 1	4030±19^{b}	4210±15^{a}	<0.0001	4.1±0.6^{a}	2.0±0.4^{b}	0.009
Week 60	Day 5	3606±64^{b}	3966±46^{a}	0.0001	12.7±0.6^{a}	6.7±0.5^{b}	<0.0001
Week 61	Day 8	3442±51^{b}	3760±40^{a}	<0.0001	17.0±0.8^{a}	11.7±0.6^{b}	<0.0001
Week 61	Day 12	3272±33^{b}	3515±30^{a}	<0.0001	21.5±0.6^{a}	17.6±0.4^{b}	<0.0001
Week 62	Day 15	3165±30^{b}	3302±25^{a}	0.002	24.2±0.6	22.8±0.6	0.094
Week 62	Day 20	3109±27	3145±29	0.369	25.6±0.4	26.3±0.4	0.195
Week 63	Day 24	3022±26	3056±97	0.749	27.7±0.5	28.2±2.4	0.848
Week 64	Day 29	2977±22	3017±30	0.304	28.7±0.4	29.3±0.7	0.472
Week 65	Day 36	3113±19^{a}	2959±43^{b}	0.005	25.5±0.4^{b}	30.4±0.9^{a}	<0.0001
Week 66	Day 45	3248±19^{a}	3091±37^{b}	0.001	22.3±0.5^{b}	27.4±0.7^{a}	<0.0001
Week 67	Day 50	3281±30	3243±45	0.500	21.4±0.6^{b}	23.6±0.7^{a}	0.022
Week 67	Day 54	3314±43^{b}	3455±34^{a}	0.017	20.4±0.8	18.9±0.5	0.116
Week 68	Day 61	3400±43^{b}	3554±35^{a}	0.012	18.1±0.7	16.6±0.5	0.084
Week 69	Day 68	3509±53^{b}	3651±36^{a}	0.035	15.3±0.6	14.3±0.5	0.213

^{a,b} Different superscripts indicate significant differences at P < 0.05.

higher than hens on the reduced-nutrient diet system (0.3%).

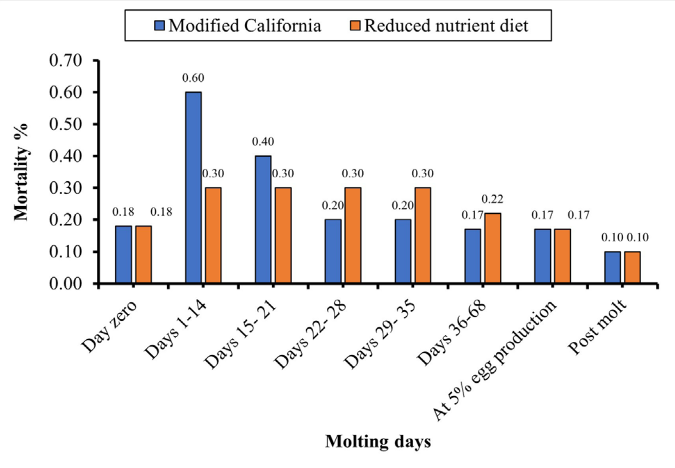

Fig. 2. Mortality % of breeder hens over time during forced molting by the two systems.

Post-molting performance

Table 5 displays the hens' performance during the post-molt period. Hens subjected to the reduced-nutrient diet showed better performance compared to those on the Modified California system. BWG of birds following the reduced-nutrient diet system showed higher levels than birds on the Modified California system, with differences ranging from 22 to 71 g (Fig. 3). The mortality rate was lower in the reduced-nutrient system than in the Modified California system. The post-molting egg production reached 79.1% in the reduced-nutrient diet system versus 74.5% in the modified California system, i.e., 88.9% and 83.7% of the first production peak (89%) (at 35 weeks) before molting respectively. Moreover, the hatchability% recorded better values for hens in the reduced-nutrient diet system compared to the Modified California system.

DISCUSSION

The hens' egg quality and production decline towards the end of the laying phase and the production is not cost-effective, so some producers urge the breeder flock to induced molt, so that the flock will be accessible for another period (Dickey *et al.* 2012). Concerns about food safety and animal welfare are becoming more widely known. The welfare of breeder hens subjected to total feed withdrawal to induce molting to acquire a second laying cycle is one of the current issues (Sariozkan *et al.* 2016). In the present study, the effectiveness of the reduced nutrient system (low-protein low-energy diet), as an alternative to the feed withdrawal method, was investigated.

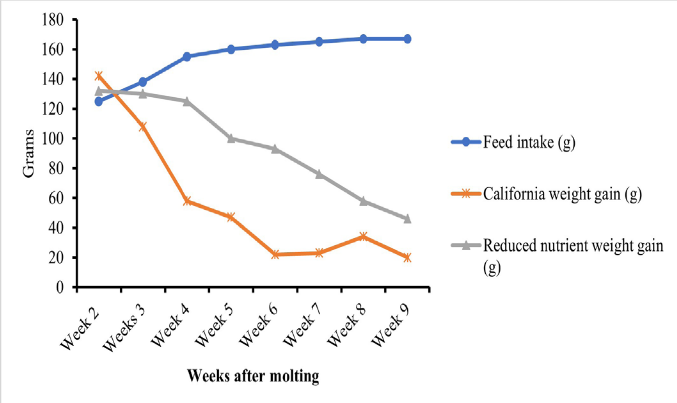

Fig. 3. Feed intake versus body weight gain of breeder hens after molting.

The physiological responses that occur during molting are employed as indicators of molt efficacy in breeder hens, including weight loss, molting feathers, and a complete stop of egg production (Toplu *et al.* 2013). It has been found that BW loss is the main factor leading to molt induction and 25 to 30% weight loss during molting is required to achieve maximal egg production post-molting (Hussein, 1996). In the current study, before molting, there was no significant differences were observed in the BW between the different systems. However, during the 1st two weeks of induced molting, the Modified California method, showed an abrupt decline and lower BW of breeder hens compared to the gradual decrease and higher BW in the reduced-nutrient method. Moreover, at the end of the molting period, BW was significantly lower in the California method than in the reduced-nutrient method, and similar results were reported by (Taboosha, and Abougabal, 2016). El-Deek and Al-Harthi (2004) demonstrated that, the feed withdrawal molt was significantly lower in the BW within 14 d of molting compared to the feed-restricted and the

Table 5. Performance of breeder hens after molting.

Molt system	Age/week after 5 % production	Feed intake (g)	Body weight gain (g)	Mortality %	Egg production %	Fertility %	Hatchability %
Modified California	Week 2	125	142	0.17	15.3	65	50
	Week 3	138	108	0.19	25.6	78	65
	Week 4	155	58	0.2	35.2	82	70
	Week 5	160	47	0.2	55.8	85	75
	Week 6	163	22	0.19	70.1	85	78
	Week 7	165	23	0.19	73.2	90	82
	Week 8	167	34	0.21	74.5	90	85
	Week 9	167	20	0.19	74.5	90	85
Low nutrient diet	Week 2	125	132	0.16	18.2	75	50
	Week 3	138	130	0.15	30.3	82	65
	Week 4	155	125	0.15	45.2	82	70
	Week 5	160	100	0.16	65.6	85	75
	Week 6	163	93	0.17	75.1	85	78.3
	Week 7	165	76	0.19	77.2	90	80
	Week 8	167	58	0.2	79.5	91	83.5
	Week 9	167	46	0.2	79.1	91	85.3

other groups, however, from 15-58 d the BW improved in the fasted group compared to the other treatments.

The BW loss for hens in the Modified California system was significantly higher in the first 12 days of molting (21.5%), compared to the reduced-nutrient system (17.6%), this could be attributed to the fasting and appetite loss during this period in the Modified California method, which leads to decrease in muscle mass and utilization of adipose tissue (El-Deek and Al-Harthi, 2004). These results agreed with Onbasilar and Erol (2007) who showed that the California group lost considerably more BW than the other groups. El-Deek and Al-Harthi (2004) stated that, in comparison to the alternative molting methods, molting by fasting for 14 days caused a considerably larger loss of BW. The maximum BW loss achieved earlier in the Modified California system was (28.7% after 29 days), while in the low-nutrient system was (30.4% after 36 days), which may be related to the regression of the reproductive tract, decreased liver weight, and depletion of fat which is proportional to the BW loss (Park *et al*., 2004a; Khajali *et al*., 2007). These findings agreed with Webster (2003) who planned that, the desired weight loss varies from 15% to 35% during the molting period. Petek and Alpay (2008) and Aygun (2013) reported that, during the molting period, BW loss should be 19.70% and 29.77%, respectively. Keshavarz and Quimby (2002) observed 30.8% weight loss following continuous feed withdrawal for 14 d.

Birds subjected to the Modified California system went out of egg production by day 8, while the reduced-nutrient group ceased egg production by day 14 of the experiment. This finding was undoubtedly expected because hens on the fasting methods did not receive any nutrients to maintain egg production. Taboosha *et al*. (2016) showed that the California-treated birds stopped producing eggs on day 7, whereas the standard method (corn diet) stopped producing eggs on day 11.6 of the experiment. El-Deek and Al-Harthi (2004) observed that the complete cessation in breeder hens occurred after 8 days of fasting, while Moustafa *et al*. (2010) recorded the complete cessation after 9 days of fasting.

The effectiveness of molting procedures other than traditional feed withdrawal is greatly determined by the performance outcomes (Sariozkan *et al*., 2016). The post-molt feed consumption wasn't significant between the different groups, this result is consistent with findings made by Petek and Alpay (2008) and Sgavioli *et al*. (2013) who observed no significant effect of the various molting methods on the post-molt FI, indicating that, the different treatments had no long-term negative effects on the breeder performance. Moreover, Ahmad and Roland (2003) reported that the feed restriction on molted Dekalb Delta chickens had no discernible influence on their BW or FI. The highest post-molt BWG results were observed in the low-nutrient group, compared to the Modified California group, which revealed that the low-energy low-protein molt diet was considered a better molting method in terms of post-molt BWG as compared to the other molting treatment. This finding agreed with previous studies conducted by Onbaşılar *et al*. (2007) who stated that the BWG and feed efficiency of hens in the whole grain treatment was better than that of hens in the fasted group.

Other performance parameters such as morality rate were significantly ($P < 0.05$) different among the different treatments as the reduced-nutrient group showed a lower mortality rate during the 1st twenty days of molting and in the post-molt period compared to the fasted group. These results could be attributed to the stressful conditions due to fasting in the modified California method and the lower BW and BW gain which negatively affects the mortality rate of hens (Moustafa *et al*., 2010). Soe *et al*. (2007) mentioned that there were no significant differences ($P > 0.05$) in mortality among the starved and low-protein and low-energy molt diet during the experimental period. Sariozkan *et al*. (2016) stated that the majority of performance indicators, including feed consumption, FCR, and mortality of non-feed removal groups, were similar to those of the feed withdrawal group. However, Biggs *et al*. (2003) found that the post-molt mortality for the corn-molt diet was 4.8%, compared to a mortality of 3.6% for the 10-day feed withdrawal treatment.

Although 5% of egg production was restored earlier in the Modified California system, than in the reduced-nutrient system, the post-molt hen egg production% results were significantly improved in the reduced-nutrient method than in the modified California group, These results may be related to the higher post molt BWG and lower mortality observed in the low nutrient group, Seo *et al*. (2001) and Biggs *et al*. (2003 and 2004) showed that the non-feed removal-induced molting boosted the egg production in a manner comparable to the limited feeding techniques. According to Onbaşılar *et al*. (2007), there were no significant variations in the post-molt egg production among the different groups that underwent molts using the California and whole grain diet methods. On the other hand, Biggs *et al*. (2003) demonstrated that there were some variations in the post-molt egg production (wk. 5 to 44) between the different treatments, as the corn molt diets produced fewer eggs than the 10-d feed withdrawal treatments. Additionally, Reddy *et al*. (2008) revealed that the fasting force molting approach appeared to produce more eggs than the zinc oxide method in broiler breeder hens.

The peak of egg production reached 79.1% in the reduced-nutrient group versus 74.5% in the California group in the post-molt period, which may be due to the faster rebuilding and rejuvenating of the reproductive tract and the increased weight tissue efficiency in the reduced-nutrient group (Khajali *et al*. 2007; Hassanabadi and Kermanshahi, 2007). El-Deek and Al-Harth (2004) reported that the peak production occurred for all breeder hens at week 10, ranging from 63 to 72.9%, and there was no discernible difference between molt induced by feed restriction, high dietary zinc, and fasting. According to Moustafa *et al*. (2010), egg production increased gradually in breeder hens after feed withdrawal molting to reach its maximum values (64.5%) within 7–10 weeks. Hassanabadi and Kermanshahi (2007) showed that the peak of post-molt egg production in layer hens is 82% in the feed withdrawal method. Bell (2003) stated that when a layer hen molts at 65 weeks, her second cycle's peak production is 75 to 85%, which is comparable to that of hen that are 40 to 50 weeks old.

Forced molting in breeder hens is crucial to improve productive performance and egg quality traits like (egg fertility and hatchability) (Thirunavukkarasu *et al*., 2006). The post-molt fertility was not significantly affected among the different molt treatments, which agreed with previous research conducted by Ali and Hassan (2018) and Soomro *et al*. (2018). Reddy *et al*. (2008) reported that the control, zinc oxide, and feed withdrawal groups' mean values of fertility during the final experimental periods were 87.76, 89.76, and 88.04%, respectively. On the other hand, the hatchability% was higher in the reduced nutrient group than in the modified California group. Bell *et al*. (2003) mentioned that increased production, improved egg fertility and hatchability, and less investment in breeding farms, all had favorable benefits on the farm outcome. Soomro *et al*. (2018) recorded non-significant fertility and hatchability% values between the low-energy diet and feed withdrawal system of forced molting. Additionally, Reddy *et al*. (2008) showed no significant difference in the hatchability% by the different methods of molting. Contrarily, Fattouh (2001) found that fasting-induced molting increased the hatchability of Muscovy duck eggs by 3.2% compared to 5.1% via zinc treatments.

CONCLUSION

Induced molting through the reduced-nutrient method (low-protein low-energy diet) is an effective method to achieve the desired BW loss and improve the BW of breeder hens during the molting period. In the reduced-nutrient method, the post-molt performance results were enhanced via improved BWG, egg production, fertility, and hatchability% and reduced mortality rate compared to the modified California method, Additionally, it improved the welfare of hens that were affected by the long period of feed deprivation. So, it has been advised to be used as an alternative method to the feed withdrawal-induced molting.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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