Effects of Dietary Crude Protein Level on Production Performance and Egg Quality of "Jinghong No. 1" Laying Hens during the Late Laying Period (Postprint)

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Abstract

This experiment was conducted to investigate the effects of different dietary crude protein levels on production performance and egg quality of "Jinghong No. 1"laying hens during the late laying period, and to determine the appropriate protein level. A total of 720 41-week-old "Jinghong No. 1" commercial laying hens were randomly assigned to groups I, II, III, and IV based on measured crude protein levels (14.08%, 14.53%, 14.98%, and 15.44%, respectively), with 12 replicates per group and 15 hens per replicate. The pre-trial period was 1 week, and the formal trial period was 22 weeks. The results showed: 1) Dietary crude protein level significantly affected laying rate, average egg weight, and daily egg mass of laying hens ($P<0.05$), all of which increased linearly with increasing dietary crude protein level ($P<0.05$); dietary crude protein level also significantly affected feed-to-egg ratio of laying hens ($P<0.05$), which decreased linearly with increasing crude protein level ($P<0.05$). 2) Shell thickness in group IV was significantly higher than that in groups I and III ($P<0.05$); egg weight in group IV was significantly higher than that in groups I and II ($P<0.05$), and egg weight increased linearly with increasing dietary crude protein level ($P<0.05$). 3) Economic benefit analysis indicated that group IV had the lowest cost per egg weight and the best economic returns. Based on comprehensive analysis of production performance and economic benefits, the appropriate crude protein level for 42~64-week-old "Jinghong No. 1" laying hens was 15.44%, with an appropriate protein-to-energy ratio of 13.41 g/MJ.

Full Text

Effects of Dietary Crude Protein Level on Performance and Egg Quality of "Jinghong 1" Laying Hens during Late Production Phase

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Abstract

This study investigated the effects of varying dietary crude protein (CP) levels on the performance and egg quality of "Jinghong 1" laying hens during the late production phase to determine the optimal protein level. A total of 720 healthy "Jinghong 1" commercial laying hens aged 41 weeks were randomly allocated to four groups (I, II, III, and IV) with 12 replicates per group and 15 hens per replicate, based on measured CP levels of 14.08%, 14.53%, 14.98%, and 15.44%, respectively. Following a 1-week adaptation period, the 22-week formal trial commenced when hens reached 42 weeks of age. The results demonstrated: (1) Dietary CP level significantly affected laying rate, average egg weight, and daily egg mass ($P<0.05$), with all parameters increasing linearly as CP level rose ($P<0.05$). The feed-to-egg ratio was also significantly influenced ($P<0.05$), decreasing linearly with increasing CP level ($P<0.05$). (2) Group IV exhibited significantly greater eggshell thickness compared to Groups I and III ($P<0.05$), and significantly higher egg weight relative to Groups I and II ($P<0.05$), with egg weight increasing linearly with dietary CP level ($P<0.05$). (3) Economic analysis revealed that Group IV achieved the lowest egg weight cost and optimal economic returns. Integrating performance and economic considerations, the recommended dietary CP level for "Jinghong 1"hens aged 42–64 weeks is 15.44%, corresponding to an appropriate protein-to-energy ratio of 13.41 g/MJ.

Keywords: "Jinghong 1" laying hens; late production phase; crude protein; performance; egg quality

Introduction

Protein constitutes the fundamental material basis of life, and poultry must obtain sufficient protein through their diet to maintain growth and production. Appropriate dietary protein levels not only maximize the productive potential of laying hens but also control nitrogen excretion in manure while reducing feed costs and improving economic efficiency. The "Jinghong 1" laying hen represents an indigenous elite breed developed through years of selective breeding in China. Commercial "Jinghong 1" chicks can be sexed by feathering rate, with survival rates reaching 98% during rearing and 95% during the laying period. Peak production rates of 93–96% can be sustained for over 180 days. However, comprehensive feeding standards for this breed remain to be established. While research has addressed optimal CP levels for "Jinghong 1" hens during peak production, no studies have reported on CP requirements during the late laying phase. This experiment was designed to evaluate the effects of different CP levels on performance and egg quality in late-phase "Jinghong 1" hens, incorporating economic analysis to determine the most suitable protein level and provide foundational data for establishing a complete nutritional standard for this breed.

1.1 Experimental Design and Diets

A single-factor randomized design was employed with consistent metabolizable energy levels across treatments. Seven hundred twenty healthy "Jinghong 1" commercial laying hens aged 41 weeks were obtained from Beijing Huadu Yukou Poultry Industry Co., Ltd. and randomly assigned to four dietary treatment groups containing 14.08%, 14.53%, 14.98%, and 15.44% CP, respectively. Each group comprised 12 replicates of 15 hens, with replicates balanced for similar laying rates and daily egg mass. The adaptation period lasted 1 week, with the formal trial extending from 42 to 64 weeks of age. The corn-soybean-cottonseed meal-based diets were formulated according to the nutrient specifications for late-phase laying hens provided by Beijing Huadu Yukou Poultry Industry Co., Ltd. and the Chinese feeding standard NY/T 33-2004. Dietary composition and nutrient levels are presented in Table 1 .

Table 1 Dietary composition and nutrient levels (air-dry basis)

Items	Group I	Group II	Group III	Group IV
Ingredients				
Corn				
Soybean meal				
Cottonseed meal				
Limestone				
CaHPO				
Zeolite powder				
NaCl				
NaHCO				
Lys				
Met				
Choline chloride				
Thr				
Try				
Premix[1]				
Total				
Nutrient levels[2]				
ME (MJ/kg)				
CP	14.08%	14.53%	14.98%	15.44%

Items	Group I	Group II	Group III	Group IV
Ca				
TP				
NPP				
Met				
Lys				

[1]The premix provided per kilogram of diet: VA 1,700 IU, VB 3 mg, VB 0.024 mg, VD 3,600 IU, VE 21 IU, VK 4.2 mg, riboflavin 10.2 mg, folic acid 0.9 mg, calcium pantothenate 15 mg, nicotinic acid 45 mg, pyridoxine 5.4 mg, biotin 0.15 mg, Cu 6.8 mg, Fe 66 mg, Zn 83 mg, Mn 80 mg, I 1 mg, Se 0.3 mg.

[2]CP was measured value, while other nutrient levels were calculated values.

1.2 Management

The trial was conducted at the Zhuozhou Experimental Station of China Agricultural University. The closed housing system featured longitudinal negative-pressure ventilation with evaporative cooling pads during summer, maintaining ambient temperatures between 18–28°C. Lighting was provided from 06:00 to 22:00 (16 h daily) at 10–20 lx intensity. Hens were housed in three-tiered step cages and fed mash diets with free access to water and feed.

1.3.1 Crude Protein Level Determination

Dietary CP content for each group was determined using a FOSS automatic Kjeldahl nitrogen analyzer according to GB/T 6432-1994.

1.3.2 Performance Metrics

Daily egg number and egg weight were recorded per replicate to calculate laying rate, average egg weight, and daily egg mass. Feed intake was measured every two weeks per replicate to determine average daily feed intake (ADFI) and feed-to-egg ratio. At trial initiation, three hens from one cage per replicate were selected and weighed monthly to monitor body weight changes and calculate average weekly body weight gain.

1.3.3 Egg Quality Determination

At 64 weeks of age, 30 eggs per group were randomly selected for quality assessment. Eggshell strength was measured using an F0241 Eggshell Force Reader (Orka Technology Ltd.). Eggshell thickness was determined with a TI-PVX micrometer (Orka Technology Ltd.). Yolk color and Haugh units were analyzed using an Egg Analyzer™ (Orka Technology Ltd.). Yolk weight, shell weight, and egg weight were measured using an electronic balance (precision 0.01 g). Percentages of yolk, albumen, and shell were calculated as ratios to egg weight.

1.4 Statistical Analysis

Data were analyzed using SPSS 20.0 software via General Linear Model (GLM) procedures with Duncan's multiple comparison tests. Linear and quadratic polynomial contrasts evaluated CP level effects, with $P<0.05$ considered statistically significant.

2.1 Effects of Dietary Crude Protein Level on Performance of Jinghong Hens during Late Production

As shown in Table 2 , dietary CP level significantly affected laying rate, average egg weight, daily egg mass, and feed-to-egg ratio ($P<0.05$). Group I exhibited significantly lower laying rate compared to other groups ($P<0.05$), while Group IV showed significantly higher laying rate than Groups I and II ($P<0.05$), with laying rate increasing linearly with dietary CP level ($P<0.05$). Average egg weight in Group I was significantly lower than in other groups ($P<0.05$), with no significant differences among Groups II, III, and IV ($P>0.05$), though average egg weight increased linearly with CP level ($P<0.05$). Daily egg mass in Group I was significantly lower than other groups ($P<0.05$), while Group IV was significantly higher than Groups I and II ($P<0.05$), increasing linearly with CP level ($P<0.05$). Group IV demonstrated the lowest feed-to-egg ratio, which was significantly lower than Groups I and II ($P<0.05$), decreasing linearly with increasing dietary CP level ($P<0.05$). Dietary CP level did not significantly affect ADFI or average weekly body weight gain ($P>0.05$), though all groups exhibited negative body weight gain that increased linearly with dietary CP level ($P<0.05$).

Table 2 Effects of dietary crude protein level on performance of Jinghong laying hens during late stage of egg production (42 to 64 weeks of age) (n=12)

Items	Group I	Group II	Group III	Group IV	P-value	Linear P-value	Conic P-value
Laying rate/%	79.29	82.56	83.97	86.16	<0.001	<0.001	
Average egg weight/g	60.01	61.38	61.00	61.49	<0.001	<0.001	
Daily egg production/g	47.50	50.48	51.16	52.67	<0.001	<0.001	
ADFI/(g/d)							
Feed/egg	2.68	2.52	2.44	2.33	<0.001	<0.001	

Items	Group I	Group II	Group III	Group IV	P-value	Linear P-value	Conic P-value
Average weekly body weight gain/(g/week)							

In the same column, values with no letter or the same letter superscripts indicate no significant difference (P>0.05), while different letters indicate significant difference (P<0.05). The same applies below.

2.2 Effects of Dietary Crude Protein Level on Egg Quality of Jinghong Hens during Late Production

Table 3 shows that dietary CP level significantly affected eggshell thickness and egg weight (P<0.05). Group IV exhibited significantly greater eggshell thickness than Groups I and III (P<0.05), and significantly higher egg weight than Groups I and II (P<0.05), with egg weight increasing linearly with dietary CP level (P<0.05). Dietary CP level did not significantly affect eggshell strength, Haugh units, yolk color, or percentages of yolk, albumen, or shell (P>0.05). However, Haugh units and shell percentage decreased linearly with increasing dietary CP level (P<0.05).

Table 3 Effects of crude protein level on egg quality of Jinghong laying hens during late stage of egg production (64 weeks of age) (n=30)

Items	Group I	Group II	Group III	Group IV	P-value	Linear P-value	Conic P-value
Eggshell thickness/mm	0.270	0.275	0.259	0.280	<0.001		
Eggshell strength/(N/kg)							
Egg weight/g	61.82	62.52	62.94	64.93			
Haugh color							
Albumen weight/egg weight/%							
Yolk weight/egg weight/%							

Items	Group I	Group II	Group III	Group IV	P-value	Linear P-value	Conic P-value
Eggshell weight/%							

2.3 Economic Analysis of Dietary Crude Protein Level

Table 4 demonstrates that egg weight cost decreased with increasing dietary CP level, with Group IV achieving the lowest cost—reductions of 0.81, 0.44, and 0.26 yuan/kg compared to Groups I, II, and III, respectively. Combined with performance data showing Group IV attained optimal laying rate, average egg weight, and daily egg mass with the lowest feed-to-egg ratio, the 15.44% CP level represents the most economically favorable recommendation.

Table 4 Effects of dietary crude protein level on economic cost of Jinghong laying hens during late stage of egg production

Items	Group I	Group II	Group III	Group IV
Feed cost/(yuan/t)				
Feed/egg				
Egg weight cost/(yuan/kg)				

3.1 Effects of Dietary Crude Protein Level on Performance

Yin et al. [3] reported that 12.3% CP could meet the requirements for normal egg production and weight maintenance in 43-47-week-old Roman hens, while 14.8% CP supported maximum egg production. In the current study, the 14.08% CP diet, despite maintaining consistent amino acid levels with other treatments, resulted in significantly lower laying rate, average egg weight, and daily egg mass compared to other groups, indicating that CP levels as low as 14.08% adversely affect late-phase performance in Jinghong hens. Qi et al. [4] found that 15.00% CP optimized performance and egg quality in late-phase Xinyang greenshell hens (44-56 weeks). Zhang et al. [5] reported that poultry have minimum requirements for non-essential amino acids or small peptides, and that production performance cannot be improved by supplemental synthetic amino acids when dietary CP falls below a certain threshold. In this experiment, no significant performance differences were observed between the 14.98% and 15.44% CP groups, suggesting that 14.98% CP could meet production requirements. However, from a practical production standpoint, the 15.44% CP group increased laying rate by 2.19 percentage points, daily egg mass by 1.51 g, and decreased feed-to-egg ratio by 0.11 compared to the 14.98% CP group. Therefore, 15.44% CP is recommended for late-phase Jinghong hens.

The theory that poultry "eat for energy" posits that dietary energy level is the primary factor affecting feed intake, with CP level having minimal influence.

This was supported by our findings where CP level did not significantly affect feed intake when energy levels were constant. Adeyemo et al. [6] reported that dietary CP level significantly affected feed conversion efficiency, with feed-to-egg ratio decreasing markedly as CP increased from 14% to 17%, consistent with our results. Wang et al. [7] suggested that maintaining a protein-to-energy ratio of 11.94–14.33 g/MJ was appropriate for sustaining laying performance, with performance increasing progressively as the ratio increased. In this study, the protein-to-energy ratio increased from 12.23 to 13.41 g/MJ with rising dietary CP levels, accompanied by improvements in laying rate, average egg weight, and daily egg mass. Therefore, from the perspective of protein-to-energy ratio, 13.41 g/MJ is recommended as optimal for late-phase Jinghong hens.

Post-peak laying hens typically experience negative nutrient balance, resulting in significant weight loss. Yin et al. [3] fed 15 dietary CP levels to 43-week-old Roman hens and observed that body weight decreased with declining CP levels, with 12.3% CP required to maintain constant body weight. In our study, all groups experienced varying degrees of body weight loss by 64 weeks compared to 42 weeks (differences not significant), with the magnitude of weight loss decreasing linearly with increasing dietary CP level. This may be attributed to the transition to relatively lower-CP diets while the flock maintained high production levels (79.29–86.16%) throughout the late phase, resulting in relative protein deficiency and consequent weight loss. Our finding that approximately 15.5% CP could not maintain constant body weight differs from Yin et al. [3], possibly due to differences in breed, trial duration, and production performance.

3.2 Effects of Dietary Crude Protein Level on Egg Quality

Adeyemo et al. [6] reported that dietary CP level (14–17%) significantly affected eggshell thickness, with the lowest CP level (14%) producing the thinnest shells. In our study, the highest CP group (15.44%) exhibited maximum eggshell thickness, though the lowest CP group (14.08%) did not show the minimum thickness, suggesting that eggshell thickness does not necessarily increase linearly with dietary CP level—a mechanism requiring further investigation.

Almeida et al. [8] found that dietary CP levels (15% and 18%) did not significantly affect eggshell strength in 20–32-week-old Hy-Line W-36 hens. Guo [9] similarly reported no significant effects of varying CP levels (15.50%, 16.50%, and 17.25%) on eggshell strength in 28–34-week-old Huafeng hens, consistent with our findings. Previous studies have demonstrated that egg weight increases linearly with dietary CP level [10–11], corroborating our results. Almeida et al. [8] suggested that increased dietary CP raises egg weight, and the negative correlation between Haugh units and egg weight leads to decreased Haugh units. In our study, although Haugh units did not differ significantly among groups, they showed a significant linear correlation with dietary CP level, decreasing gradually as CP increased.

Some studies have reported that yolk color deepens significantly with decreasing dietary CP level, attributing this to relatively higher corn content increasing dietary lutein levels [12-13]. In contrast, our study found no effect of CP level on yolk color, likely due to minimal variation in dietary corn proportions among treatments.

Under our experimental conditions, the optimal dietary CP level for "Jinghong 1" laying hens during the late production phase (42-64 weeks) is 15.44%, with a recommended protein-to-energy ratio of 13.41 g/MJ.

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Note: Figure translations are in progress. See original paper for figures.