AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-201711.01034

Effect of Dietary Crude Protein Level on Production Performance of Jining Bairi Egg-type Breeder Chickens (Postprint)

Authors: Yin Ruoxin, Cao Bingjian, Hu Xiyi, Ding Xiangwen, Su Pengcheng, Song Zhigang

Date: 2017-10-23T00:00:00+00:00

Abstract

This study investigated the effects of dietary crude protein level on the production performance of Jining Bairi laying breeder hens, established a factorial model for protein requirement, and determined the dietary crude protein requirement. A single-factor completely randomized design was adopted with dietary crude protein levels of 13%, 14%, 15%, 16%, and 17%, while other nutritional indices remained consistent. A total of 525 healthy Jining Bairi laying breeder hens at 40 weeks of age with similar body weight were randomly divided into 5 groups, with 5 replicates per group and 21 hens per replicate. The pre-trial period was 7 days, and the experimental period was 56 days. The results showed that: 1) Dietary crude protein level had an extremely significant effect on average daily crude protein intake (ADCPI) of Jining Bairi laying breeder hens ($P<0.01$), and ADCPI increased significantly with increasing dietary crude protein level ($P<0.05$). 2) Dietary crude protein level had significant effects on egg number, laying rate, average egg weight, and average daily egg mass (ADEM) of Jining Bairi laying breeder hens aged 41-48 weeks ($P<0.05$), and had an extremely significant effect on feed-to-egg ratio ($P<0.01$); the high crude protein level groups (16%, 17%) had higher egg number, laying rate, and ADEM than the low crude protein level groups (13%, 14%, 15%). Within a certain range of dietary crude protein levels (13%-16%), egg weight tended to increase with increasing dietary crude protein level. 3) Using ADCPI as the dependent variable and average daily gain (ADG), ADEM, and metabolic body weight (BW0.75) as independent variables, the factorial model for crude protein requirement of Jining Bairi laying breeder hens was fitted as: ADCPI=0.268 0 ADG+0.271 1 ADEM+3.299 3 BW0.75 (R2=0.993 4). The appropriate dietary crude protein level to achieve optimal production performance for Jining Bairi laying breeder hens aged 41-48 weeks was 15.49%.

Full Text

Abstract

This experiment was conducted to investigate the effects of dietary crude protein levels on the performance of Jining Bairi breeding hens, establish a factorial model for protein requirements, and determine the optimal dietary crude protein level for this breed. A single-factor completely randomized design was employed with dietary crude protein levels of 13%, 14%, 15%, 16%, and 17%, while other nutrient indices remained consistent. A total of 525 healthy 40-week-old Jining Bairi breeding hens with similar body weight were randomly allocated into 5 groups, each consisting of 5 replicates with 21 hens per replicate. The pre-test period lasted 7 days, followed by a 56-day experimental period. The results showed: 1) Dietary crude protein level had an extremely significant effect on average daily crude protein intake (ADCPI) ($P<0.01$), with ADCPI increasing significantly as dietary crude protein level increased ($P<0.05$). 2) Dietary crude protein level significantly affected egg number, laying rate, average egg weight, and average daily egg mass (ADEM) during weeks 41–48 ($P<0.05$), and had an extremely significant effect on feed-to-egg ratio ($P<0.01$). The high crude protein groups (16% and 17%) exhibited higher egg number, laying rate, and ADEM compared to the low crude protein groups (13%, 14%, and 15%). Within a certain range (13%–16%), average egg weight tended to increase with rising dietary crude protein level. 3) Using ADCPI as the dependent variable and average daily gain (ADG), ADEM, and metabolic body weight (BW^0.75) as independent variables, the factorial model for crude protein requirements was fitted as: ADCPI = 0.2680 ADG + 0.2711 ADEM + 3.2993 BW^0.75 (R^2 = 0.9934). The suitable dietary crude protein level for optimal performance of Jining Bairi breeding hens aged 41–48 weeks was determined to be 15.49%.

Keywords: crude protein; Jining Bairi chicken; performance; crude protein requirement

Introduction

Protein constitutes a primary component of poultry body composition, accounting for approximately 21% of live body protein in laying hens after digestive tract contents are removed, and about 12.8% of whole egg protein. Protein influences poultry immune function, regulates hormones and antibody levels, and enhances defense mechanisms. Dietary crude protein level significantly affects body weight gain, feed intake, feed conversion ratio, and laying rate in poultry, though some reports indicate that it does not significantly impact average daily feed intake (ADFI), average daily gain (ADG), or feed-to-gain ratio in local chicken breeds.

Recent research has extensively investigated the nutritional requirements of local chicken breeds, covering protein and energy needs for multiple varieties. Due to differences in breed, climate, management system, body size, and physiological stage, the dietary crude protein requirements vary among different laying hen breeds. For instance, Huainan Partridge chickens have different crude protein requirements at different production stages: 14.0% during early lay (weeks 19–23) at 11.56 MJ/kg metabolizable energy (ME), 16.0% at peak production (weeks 24–40) at 11.68 MJ/kg ME, and 12.9% in late lay (weeks 44–51) at 11.68 MJ/kg ME. Beijing You chickens require 15.2% crude protein at peak production.

Jining Bairi chicken, a dual-purpose local breed originating from Jining, Shandong Province, is named for its early maturity, with some individuals reaching sexual maturity around 100 days of age. The Jining Bairi chicken breeding farm currently maintains over 20,000 breeding birds, which have been distributed to more than 20 provinces across China with annual sales exceeding 10 million birds. However, no studies on its crude protein requirements have been reported. This experiment aimed to investigate the effects of dietary crude protein levels on the performance of Jining Bairi breeding hens to obtain parameters for crude protein requirements and provide a scientific basis for establishing feeding standards and production practices.

Materials and Methods

1.1 Experimental Design

This experiment was conducted at the Jining Bairi chicken breeding farm. A total of 525 healthy 40-week-old Jining Bairi breeding hens with similar body weight were randomly divided into 5 groups, with 5 replicates per group and 21 hens per replicate. The pre-test period lasted 7 days (at 40 weeks of age), followed by a 56-day experimental period (weeks 41–48). A single-factor completely randomized design was employed with dietary crude protein levels of 13% (Group A), 14% (Group B), 15% (Group C), 16% (Group D), and 17% (Group E), while other nutrient indices remained consistent across treatments.

1.2 Experimental Diets

Corn-soybean meal-based diets were formulated according to the NY/T 33-2004 "Feeding Standard of Chickens" and adjusted based on practical production conditions. The composition and nutrient levels of experimental diets are presented in Table 1 . Diet samples from each group were analyzed for crude protein content using the Kjeldahl method.

Table 1 Composition and nutrient levels of experimental diets (air-dry basis), %

Note: 1) Premix provided per kilogram of diet: VA 230,000 IU, VD 100,000 IU, VE 1,000,000 IU, VK 60 mg, VB 60 mg, VB 350 mg, VB 100 mg, VB 0.6 mg, Cu 0.5–2.5 g, Fe 1.6 g, Mn 2.5 g, Zn 2.5 g, Se 10–18 mg, biotin 5 mg, choline 16 g, folic acid 32 mg, nicotinic acid 2,000 mg, pantothenic acid 400 mg. 2) Crude protein was measured value; others were calculated values.

1.3 Management Practices

Hens were housed in a three-tier step cage system under natural light supplemented with artificial lighting to provide 16 hours of light daily. Dry mash feed was provided twice daily with four redistributions, allowing ad libitum access to feed. Nipple drinkers provided free access to water. Eggs were collected once daily in the afternoon. Routine management followed the standard operating procedures established by the Jining Bairi chicken breeding farm.

1.4 Measurements

Feed Intake: During the experimental period, 14-day batches of experimental diets were prepared for each replicate, with total feed amount and residual feed accurately recorded. Feed intake was calculated every two weeks for each replicate to determine ADFI and average daily crude protein intake (ADCPI). Feed intake = total feed amount - residual feed; ADFI = feed intake / (number of hens per replicate × experimental days); ADCPI = ADFI × dietary crude protein level.

Body Weight: Every two weeks during the experimental period, 6 hens per replicate were randomly selected and weighed to calculate average body weight, ADG, and metabolic body weight (BW^0.75). ADG = (final body weight - initial body weight) / experimental days.

Survival Rate: Daily mortality and culling numbers were recorded for each replicate, along with body weight, to calculate survival rate. Survival rate (%) = (total number of hens housed - total mortality and culling) / total number of hens housed × 100.

Performance: Daily egg number and egg weight were recorded for each replicate, along with the number of unqualified eggs (broken, misshapen, sand-shell, soft-shell, etc.). Egg number, laying rate, average egg weight, average daily egg mass (ADEM), and feed-to-egg ratio were calculated.

1.5 Statistical Analysis

Data were analyzed using one-way ANOVA with SAS 9.2 software. Statistical significance was set at P<0.05, and Duncan' s multiple range test was used for pairwise comparisons when significant differences were detected. Sensitive indicators were subjected to linear and quadratic regression analysis. The factorial model for crude protein requirements was fitted using interactive data analysis.

Results

2.1 Effects of Dietary Crude Protein Level on Feed Intake, Body Weight, and Survival Rate

As shown in Table 2 , dietary crude protein level had an extremely significant effect on ADCPI (P<0.01). ADCPI increased significantly as crude protein level increased from 13% to 16% ($P<0.05$), but no significant difference was observed between the 16% and 17% groups ($P>0.05$). Dietary crude protein level had no significant effects on ADFI, average body weight, BW^0.75, ADG, or survival rate ($P>0.05$).

Table 2 Effects of dietary crude protein level on feed intake, body weight, and survival rate of Jining Bairi laying hens

Note: In the same row, values with the same letter or no letter superscripts indicate no significant difference (P>0.05), adjacent letters indicate significant difference (P<0.05), and alternate letters indicate extremely significant difference (P<0.01). The same applies to Table 3.

2.2 Effects of Dietary Crude Protein Level on Performance

Table 3 shows that dietary crude protein level significantly affected egg number, laying rate, average egg weight, and ADEM ($P<0.05$), and had an extremely significant effect on feed-to-egg ratio ($P<0.01$), but did not significantly affect the rate of unqualified eggs ($P>0.05$).

The effects on egg number, laying rate, and ADEM followed similar patterns: these parameters decreased as crude protein level increased at lower levels (13%, 14%, and 15%), reached maximum values at 16% crude protein, and then decreased at 17% crude protein. However, the high crude protein groups (16% and 17%) consistently outperformed the low crude protein groups (13%, 14%, and 15%).

Average egg weight increased significantly with rising dietary crude protein level ($P<0.05$), reaching a maximum of 44.97 g at 16% crude protein, which was 1.54 g heavier than the minimum weight of 43.43 g observed in the 13% group. Egg weight decreased when crude protein level increased to 17%. Within the range of 13%–16% crude protein, average egg weight tended to increase with dietary crude protein level, though the highest level did not produce the highest egg weight.

The feed-to-egg ratio increased with crude protein level at lower concentrations (13%, 14%, and 15%), reaching a maximum of 3.45 at 15% crude protein. It then decreased significantly at 16% crude protein ($P<0.05$) and continued to decline to a minimum of 2.90 at 17% crude protein. The differences in feed-to-egg ratio between high (16% and 17%) and low (13%, 14%, and 15%) crude protein groups were significant ($P<0.05$).

In summary, the high crude protein groups (16% and 17%) showed superior egg number, laying rate, and ADEM compared to the low crude protein groups (13%, 14%, and 15%). The 16% crude protein group achieved the highest values for egg number, laying rate, average egg weight, and ADEM, demonstrating the best overall performance. Notably, the highest crude protein level (17%) did not yield the highest performance.

Table 3 Effects of dietary crude protein levels on performance of Jining Bairi laying hens

2.3 Crude Protein Requirements of Jining Bairi Laying Hens Aged 41-48 Weeks

A factorial approach was used to establish the crude protein requirement model for Jining Bairi laying hens during weeks 41-48. Using ADCPI as the dependent variable and ADG, ADEM, and BW^0.75 as independent variables, the factorial model for crude protein requirements was fitted (Table 4). Based on the effects of dietary crude protein level on performance and the established factorial model, combined with the ADG, ADEM, and BW^0.75 values from the optimal performance group, the dietary crude protein requirement for Jining Bairi laying hens was determined to be 15.49%.

Table 4 Crude protein requirements of Jining Bairi laying hens aged 41-48 weeks

Factorial model: ADCPI = 0.2680 ADG + 0.2711 ADEM + 3.2993 BW^0.75

Discussion

3.1 Effects of Dietary Crude Protein Level on Feed Intake, Body Weight, and Survival Rate

As a local breed, Jining Bairi chickens exhibit lower performance compared to high-yielding commercial layers. In this experiment, ADFI, laying rate, ADEM, and egg weight were all relatively low compared to commercial layers. These differences in performance and breed characteristics between Jining Bairi and commercial chickens determine their distinct nutritional requirements, and feeding standards recommended for commercial layers are not suitable for Jining Bairi chickens, failing to exploit their production potential.

Poultry are known to "eat for energy," with feed intake decreasing as dietary energy level increases, while crude protein level has minimal impact on feed intake. Under consistent dietary metabolizable energy levels in this study, although the lowest crude protein group (13%) showed the highest ADFI and the highest crude protein group (17%) showed the lowest ADFI, demonstrating a trend of decreasing ADFI with increasing crude protein level, the effect was not statistically significant. This aligns with previous reports and further validates the "eat for energy" theory. ADCPI increased significantly with dietary crude protein level, mirroring the trend in crude protein levels, which is consistent with literature reports. This occurred because ADFI was not significantly affected by crude protein level while dietary crude protein levels varied, confirming that crude protein level did not significantly impact feed intake in Jining Bairi laying hens.

Breed, genetics, physiological status, management, and environmental conditions all influence crude protein requirements. Dietary crude protein level is also a major nutritional factor affecting body weight. At a given energy level, adequate crude protein intake is essential for normal physiological and productive functions, and deficiency can cause adverse effects or even mortality. This study showed that dietary crude protein level did not significantly affect body weight or ADG in Jining Bairi laying hens. Although a trend of increasing body weight with crude protein level was observed, this trend disappeared at high crude protein levels, with body weight actually decreasing from 1.46 kg in the 15% group to 1.34 kg in the 17% group. This may be because excessive crude protein levels cause digestive disturbances, impair nutrient absorption, lead to enteritis and diarrhea, and result in the production of toxic substances from undigested protein fermented by gut microbiota. The liver and kidneys may also be damaged from overloading, ultimately causing toxicity. Similar results were reported in Kangdal yellow-feathered broilers, where 17% crude protein produced poorer performance than 16%. Other studies have shown different results, with dietary nutrient levels significantly affecting body weight and daily gain in Hetian chickens, where daily gain was positively correlated with crude protein level at a given energy level, and optimal crude protein and energy levels varied by sex and growth stage. In contrast, this study demonstrated that higher crude protein levels did not necessarily result in higher body weight, and that appropriate crude protein levels are required for optimal body weight and daily gain.

Although dietary crude protein level did not significantly affect survival rate, the 17% group showed the lowest survival rate, with the primary cause of mortality being prolapse. Excessive dietary crude protein increases the frequency of large eggs, making oviposition difficult and reducing tissue elasticity around the cloaca, which prevents the oviduct from retracting properly after egg laying. Short-term feeding of high-protein diets to hens at peak production can cause a sudden increase in egg production and higher incidence of prolapse. High crude protein levels can cause nutritional imbalances that increase the likelihood of prolapse and mortality.

Nutrient requirements of laying hens are influenced by breed, management, environment, body weight, and egg production. Among factors affecting poultry productivity, heritability accounts for only 5%-10%, while 50%-95% depends on environmental conditions. The lack of significant effects of crude protein level on ADFI, body weight, BW^0.75, ADG, unqualified egg rate, and survival rate in this study may be attributed to breed characteristics or the relatively small gradient differences in dietary crude protein levels. When Huainan Partridge chickens aged 24-40 weeks were fed diets with 15%, 16%, and 17% crude protein at 11.68 MJ/kg ME, no significant effects on daily feed intake, average egg weight, or body weight were observed, consistent with our findings.

3.2 Effects of Dietary Crude Protein Level on Performance

Dietary crude protein level significantly affected the primary performance indicators of laying hens—egg number, laying rate, average egg weight, and ADEM

—consistent with previous research. As dietary crude protein level increased, laying rate and daily egg mass of Hy-Line Brown hens at peak production also increased. Crude protein level significantly affected laying rate and total egg weight of Hy-Line W-36 hens from 19 to 72 weeks. When crude protein level increased from 11.7% to 14.6%, egg production and average egg weight of Roman hens increased significantly despite no change in laying rate, demonstrating that dietary energy-protein balance significantly affects performance.

Our results also showed that at low crude protein levels (13%, 14%, and 15%), egg number and laying rate decreased as crude protein level increased, reaching maximum values at 16% crude protein, then decreasing at 17% crude protein. However, the high crude protein groups (16% and 17%) outperformed the low crude protein groups (13%, 14%, and 15%) in egg number, laying rate, and ADEM. This suggests that low crude protein diets failed to meet the requirements for egg production, while 17% crude protein exceeded the requirement for Jining Bairi laying hens.

Excessive crude protein intake is detrimental to performance, as confirmed by this study. The 16% crude protein group showed the best performance, while the highest level (17%) did not produce the best results, possibly due to reduced protein metabolism efficiency at excessive levels. This aligns with reports on Xueshan grass chickens, which have a wide adaptation range to crude protein levels in late growth stages, but both deficient (13.11%) and excessive (17.08%) levels impair performance and waste protein resources. Similar findings were reported for Luxi game chickens and Chongren Partridge chickens, where appropriate crude protein levels significantly improved egg production, laying rate, and feed-to-egg ratio in Luxi game chickens aged 21-46 weeks, while Chongren Partridge chickens were insensitive to high nutrient levels and achieved similar performance with medium levels.

Selecting appropriate crude protein levels for different production stages can improve performance and reduce costs. Huainan Partridge chickens require different crude protein levels at various stages: 20% at 1-6 weeks (11.96 MJ/kg ME), 14.0%-15.0% at 7-18 weeks (11.69-11.73 MJ/kg ME), 14.0% at 19-23 weeks (11.56 MJ/kg ME), 16.0% at 24-40 weeks (11.68 MJ/kg ME), and 12.9% at 44-51 weeks (11.68 MJ/kg ME). Similar results were found for Luxi game chickens, with optimal crude protein levels of 14.0% at 26-29 weeks, 17.0% at 30-37 weeks, and 18.5% at 38-41 weeks. This study confirms that only when dietary crude protein level matches the animal' s requirements can production potential be maximized with minimal input.

High crude protein diets have been shown to significantly increase egg weight and laying rate. When 30-52-week-old broiler breeders were fed diets with 16%, 14%, 12%, and 10% crude protein at consistent amino acid and energy levels, higher crude protein levels resulted in greater egg weight with significant differences among groups throughout the experiment. This study also demonstrated that within a certain range, average egg weight of Jining Bairi laying hens tended to increase with dietary crude protein level.

High egg production does not necessarily translate to high economic benefit; only when high production is accompanied by low feed consumption can profitability be achieved. Feed-to-egg ratio is an economic indicator reflecting input-output efficiency in production. In this study, the high crude protein groups (16% and 17%) had significantly lower feed-to-egg ratios than the low crude protein groups (13%, 14%, and 15%). While this experiment did not evaluate economic impacts, this represents a direction for future research.

Conclusion

This study demonstrated that: ADCPI of Jining Bairi laying hens increased significantly with dietary crude protein level, showing a consistent trend with dietary crude protein levels. Dietary crude protein level significantly affected egg number, laying rate, average egg weight, and ADEM, and had an extremely significant effect on feed-to-egg ratio in Jining Bairi laying hens aged 41–48 weeks. The high crude protein groups (16% and 17%) outperformed the low crude protein groups (13%, 14%, and 15%) in egg number, laying rate, and ADEM. Within the range of 13%-16% crude protein, average egg weight tended to increase with dietary crude protein level. The suitable dietary crude protein level for optimal performance of Jining Bairi laying hens aged 41–48 weeks was 15.49%.

References

[1] MAYNARD L A, LOOSLI J K, HINTZ H F, et al. Animal nutrition[M]. 7th ed. New York: Hill Book Company, 1979.

[2] YANG Feng. Animal nutrition[M]. 2nd ed. Beijing: China Agriculture Press, 2008.

[3] GLICK B, TAYLOR R L Jr, MARTIN D E, et al. Calorie-protein deficiencies and the immune response of the chicken. . Cell-mediated immunity[J]. Poultry Science, 1983, 62(9): 1889–1893.

[4] GUO Changjiang, XU Qishou. Regulatory effects of arginine on immune cell function in vitro[J]. Amino Acids Journal, 1991(1): 4–5.

[5] ROURA E, HOMEDES J, KLASING K C. Prevention of immunologic stress contributes to the growth-permitting ability dietary antibiotics chicks[J]. Journal Nutrition, 1992, 122(12): 2383–2390.

[6] JOSEPH N S, ROBINSON F E, KORVER D R, et al. Effect of dietary protein intake during the pullet-to-breeder transition period on early egg weight and production in broiler breeders[J]. Poultry Science, 2000, 79(12): 1790–1796.

[7] FU Shengyong, WU Shugeng, ZHANG Haijun, et al. Effects of dietary energy concentration and crude protein level on performance, egg quality, nitrogen and greenhouse gas excretion in laying hens[C]//Proceedings of the 11th National Animal Nutrition Symposium of Chinese Association of Animal Science and

Veterinary Medicine. Beijing: Chinese Association of Animal Science and Veterinary Medicine, 2012.

[8] SUN Yonggang, WANG Zhixiang, KANG Juanjuan, et al. Effects of different nutrient levels on performance of laying hens at peak production[J]. Feed Research, 2010(9): 20–24.

[9] ZENG Zhuoxiang, PAN Xiaojian, PENG Zengqi, et al. Effects of different protein levels in hen diets on egg quality and offspring meat quality[J]. Jiangsu Agricultural Sciences, 2006(6): 288–292.

[10] XU Meijie, LIU Xiaofei, ZHONG Jinfeng. Study on suitable energy and protein levels for Xianghuang chickens aged 14–21 weeks[J]. Journal of Domestic Animal Ecology, 2010, 31(3): 35–40.

[11] OUYANG Kehui, WANG Wenjun, LIN Shumao, et al. Effects of different nutrient levels on performance and carcass chemical composition of Chongren Partridge chickens at different stages[J]. Chinese Journal of Animal Science, 2004, 40(3): 27–29.

[12] TIAN Yadong. Study on energy and protein nutritional requirements of Gushi chickens[D]. Master' s thesis. Zhengzhou: Henan Agricultural University, 2002.

[13] ZHU Youcai. Study on dietary protein level of Huainan Partridge chickens[D]. Master' s thesis. Hefei: Anhui Agricultural University, 2013.

[14] ZHOU Yongxiao. Study on suitable crude protein level for Beijing You chickens at peak production[D]. Master' s thesis. Luoyang: Henan University of Science and Technology, 2012.

[15] JIANG Shuzhen, CHEN Guanjun, YANG Weiren, et al. Crude protein requirement of Luxi game chickens during laying period[J]. Chinese Journal of Animal Nutrition, 2013, 25(12): 2865–2872.

[16] LEESON S, CASTON L J. Response of laying hens to diets varying in crude protein or available phosphorus[J]. The Journal of Applied Poultry Research, 1996, 5(3): 289–296.

[17] MORRIS T R. The effect of dietary energy level on the voluntary calorie intake of laying birds[J]. British Poultry Science, 1968, 9(3): 285–295.

[18] GUNAWARDANA P, ROLAND D A, BRYANT M M. Effect of energy and protein on performance, egg components, egg solids, egg quality, and profits in molted Hy-line W-36 hens[J]. The Journal of Applied Poultry Research, 2008, 17(4): 432–439.

[19] QIN Jiangfan, LIANG Zuman, FANG Ruikun. Effects of different energy concentrations, protein levels, and choline on late growth performance of Kangdal yellow-feathered broilers[J]. Feed Review, 2002(12): 30–31.

[20] YANG Ye, LI Zhongrong, FENG Yulan. Study on dietary energy and crude protein levels for Hetian chickens[J]. Fujian Journal of Agricultural Sciences, 2001, 16(1): 42-48.

[21] ZONG Wenli, BAI Xiujuan. Effects of different nutrient level diets on performance of growing Guifei chickens[J]. Journal of Economic Animal, 2006, 10(4): 203-205.

[22] DING Changchun, LI Lihu. Causes and countermeasures of prolapse in caged breeding hens[J]. Poultry and Disease Prevention, 1998(10): 26.

[23] LI Cuiping. Analysis of causes and prevention measures for hen prolapse[J]. Liaoning Animal Husbandry and Veterinary Medicine, 1986(1): 12-14.

[24] PANDA A K, RAMA RAO S V, RAJU M V L N, et al. Effect of nutrient density on production performance, egg quality and humoral immune response of brown laying (Dahlem Red) hens in the tropics[J]. Tropical Animal Health and Production, 2012, 44(2): 293-299.

[25] JUNQUEIRA O M, DE LAURENTIZ A C, DA SILVA FILARDI R, et al. Effects of energy and protein levels on egg quality and performance of laying hens at early second production cycle[J]. The Journal of Applied Poultry Research, 2006, 15(1): 110-115.

[26] YANG Ning. Modern chicken production[M]. Beijing: Beijing Agricultural University Press, 1994.

[27] ZHU Youcai, LI Lümu, ZHAN Kai, et al. Effects of dietary crude protein level on performance of Huainan Partridge breeding hens[J]. China Poultry, 2013, 35(8): 25-29.

[28] SUN Yonggang. Determination of suitable protein and methionine requirements for laying hens at peak production under low energy levels and study on ideal protein pattern[D]. Master' s thesis. Zhengzhou: Henan Agricultural University, 2010.

[29] HUANG Baohua, ZHANG Guizhi, SHI Tianhong, et al. Effects of different nutrient levels on performance of laying hens aged 19-72 weeks[J]. Shandong Poultry, 2000(1): 10-13.

[30] YIN Qingqiang, HAN Youwen, TENG Bing, et al. Study on protein and essential amino acid model for laying hens at peak production[J]. Journal of Northeast Agricultural University, 1996, 27(3): 259-265.

[31] KHAJALI F, KHOSHOUIE E A, DEHKORDI S K, et al. Production performance and egg quality of Hy-line W36 laying hens fed reduced-protein diets at a constant total sulfur amino acid:lysine ratio[J]. The Journal of Applied Poultry Research, 2008, 17(3): 390-397.

[32] NOVAK C, YAKOUT H M, SCHEIDELER S E. The effect of dietary protein level and total sulfur amino acid:lysine ratio on egg production parameters

and egg yield in Hy-line W-98 hens[J]. Poultry Science, 2006, 85(12): 2195-2206.

[33] ZHU Jiangning. Study on suitable protein level for Xueshan grass hens in late stage[D]. Master' s thesis. Nanjing: Nanjing Agricultural University, 2005.

[34] CHEN Guanjun, YANG Weiren, YANG Zaibin, et al. Effects of dietary crude protein level on performance and egg quality of Luxi game chickens[J]. Chinese Journal of Animal Nutrition, 2012, 24(10): 2028-2035.

[35] OUYANG Kehui, WANG Wenjun, LIN Shumao, et al. Effects of energy and protein levels on performance of Chongren Partridge chickens[J]. Chinese Journal of Poultry, 2003, 7(1): 10-13.

[36] BOWMAKER J E, GOUS R M. Quantification of reproductive changes and nutrient requirements of broiler breeder pullets at sexual maturity[J]. British Poultry Science, 1989, 30(3): 663-675.

[37] LOPEZ G, LEESON S. Response of broiler breeders to low-protein diets. 1. adult breeder performance[J]. Poultry Science, 1995, 74(4): 685-695.

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

Source: ChinaXiv —Machine translation. Verify with original.