飼料中の粗タンパク質および代謝エネルギー水準が若雌鶏の産卵成績におよぼす影響

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Effect of Dietary Crude Protein and Metabolizable Energy Levels on the Performance of Laying Hens

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The present experiment was conducted to determine the extent the performance of young laying hen was affected by dietary crude protein (CP) and metabolizable energy (ME) levels, preceeding a series of experiment to determine the requirement of each essential amino acid.

Seven hundred twenty pullets of a commercial strain were housed two birds per cage in an open convention-ventilated laying house and fed twelve diets *ad libitum* from 150 to 255 days of age. Three replicate (240 birds per replicate) were involved. Mean daily temperature ranged from 15° to 25°C during the experimental period. Experiment had a 4×3 factorial arrangement of treatment with four levels of CP and three levels of ME.

The diets were formulated for methionine, lysine and tryptophan to reach 85, 95, 105 or 115% of the NRC recommendations and contained graded levels of dietary ME (2,700, 2850 and 3,000 kcal/kg).

Significant diet differences for feed intake, egg production, egg weight, egg mass, body weight gain and feed conversion ratio were noted. Increasing the dietary energy resulted in reduced feed intake and a general tendency to increase energy intake. But feed consumption was not affected by dietary CP levels. Increasing the protein level of the diet resulted in increased protein intake but had no effect on energy intake. Throughout the whole experimental periods, egg production increased with increasing CP levels. The egg production rate was not affected by ME level till 192 days of age, but it tended to decrease with increasing ME level after that age. Egg weight increased with age on all diets. It increased with increasing CP level until 234 days of age, but was not affected by ME level throughout all experimental period. Since egg weight increased with age on all diets and egg production rate increased with increasing CP levels, egg mass also increased with age and by CP levels in the similar way as egg weight and production rate. As protein and energy levels increased, efficiency of feed utilization increased.

The present study showed that the CP level which maximized hen performance was 14.5% or more across all ME levels and on the protein requirements of laying hens indicated that for maximum production of about 90%, hens required about 18 grams of protein per day. Present experiment also have suggested that in a moderate environmental temperature (from 15° to 25°C) ME levels of 2,700-2,850 kcal per kg diet might give economical results. The daily energy requirement of the hens for maximum production of about 90% ranged from approximately 310 to 330 kcal ME per day.

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Key words : protein level, energy level, laying hen, egg production

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Introduction

There are many published reports on amino acid requirements of laying hens. The values reported do not always agree well, because of variations in genetic, dietary and environmental factors (SCOTT *et al.*, 1976). Crude protein (CP) and metabolizable energy (ME) are the main dietary factors that influence amino acid requirements. It is generally accepted that feed intake of poultry is governed under most conditions by the caloric intake, and the ME intake is relatively constant over a range of ME levels. However, it has been demonstrated recently that energy intake is not constant over all dietary energy cocentrations, being lower at the lower energy levels and higher at the higher energy concentrations (MORRIS, 1968 ; GOUS *et al.* 1987). Thus, amino acid requirements should not be stated either as a percentage of the ration or as ratios to the energy level. On the other hand, amino acid requirements increase with an increase of dietary crude protein levels (BOOMGAADT and BAKER, 1971 ; D' MELLO and WEIS, 1970 ; EATER and BAKER, 1980 ; KOIDE *et al.*, 1990 ; ROBINS, 1987). However, it is not clear whether the amino acid requirement expressed as a percent of CP is constant, increase or decrease with increasing dietary CP levels. Protein quality rather than protein quantity is important and therefore amino acid levels have to be given consideration.

The present study was conducted to determine the extent the performance of young laying hen was affected by dietary CP and ME levels, and to obtain the basic information of laying hens proceeding a series of experiments to determine the requirement of each essential amino acid. Some amino acids such as methionine, lysine and tryptophan were reached to be 85 to 115% of NRC recommendation and protein levels were from 10.5 to 14.5% as a results.

Materials and Methods

1. Animals

Commercial stock of laying pullets (Shaver Star-Cross) at 150 days of age were arranged in 36 rows of 20 birds. Each row consisted of 10-two bird cages with a common food trough. The rows were arranged in one single-sided block, two tiers high in an open convention-ventilated laying house. The experiment began in September. Mean daily temperature ranged from 15° to 25°C during the experimental period. In the present study, 720 pullets were assigned to one of twelve treatments. Each treatment was replicated three times (20 birds per replicate) for a total of 60 birds per treatment. Twelve diets consisting of four protein and three energy levels were fed ad libitum for 105 days from 150 to 255 days of age.

2. Diets

The compositions of the four basal diets used ; (low CP and low ME, high CP and low ME, low CP and high ME and high CP and high ME) are shown in Table 1. The low and high ME levels were formulated to be 2,700 and 3,000·kcal/kg diet, respectively. The low and high CP levels were formulated for methionine, lysine and tryptophan to reach 85 or 115% of the NRC (1984) recommendations. Blending low

Table 1. Composition of experimental diets (%)

Diet No.	1	4	9	12
Ratio to NRC (%)	85	115	85	115
Corn	69.54	64.80	81.60	73.80
Wheat bran	15.0	14.40	—	—
Soybean meal (44% CP)	1.55	4.90	3.55	7.35
Fish meal (60.2% CP)	1.55	4.90	3.55	7.35
Soybean oil	1.0	1.0	1.0	1.90
$CaCO_3$	7.40	7.20	7.50	7.00
$CaHPO_4$	2.60	1.40	1.50	1.50
Amino acid mixture[1]	0.46	0.29	0.131	0.20
NaCl	0.30	0.30	0.30	0.30
Vitamin-mineral mixture[2,3]	0.5	0.5	0.5	0.5
Choline-Cl	0.10	0.10	0.10	0.10
CP	10.59	13.63	11.37	14.53
ME (kcal/kg)	2703	2699	3005	3001
Ca	3.56	3.41	3.45	3.49
Available P	0.39	0.38	0.36	0.37
Amino acid				
Arg	0.608	0.823	0.667	0.906
Gly	0.496	0.698	0.540	0.746
Ser	0.499	0.659	0.522	0.700
His	0.229	0.301	0.252	0.331
Ile	0.425	0.575	0.483	0.649
Leu	1.024	1.230	1.177	1.391
Lys	0.544	0.736	0.544	0.735
Met	0.272	0.368	0.272	0.369
Cys	0.196	0.265	0.196	0.266
Phe	0.471	0.598	0.545	0.681
Tyr	0.421	0.502	0.478	0.561
Thr	0.402	0.528	0.474	0.610
Trp	0.128	0.161	0.119	0.161
Val	0.554	0.705	0.615	0.778

1) Added to meet NRC values (1984)

2) Vitamin premix provides per kilogram of diet: vitamin A, 11,000 IU; cholecalciferol, 1,100 ICU; riboflavin, 4.4 mg; choline chloride, 220 mg; vitamin B_{12}, 6.6 μg; vitamin B_6, 2.2 mg; menadione sodium bisulfite, 1.1 mg; folic acid, 0.55 mg; biotin, 0.11 mg; thiamin, 2.2 mg and ethoxyquin, 125 mg.

3) Trace mineral mix provides (in milligrams per kg diet): Mn, 60; Zn, 50; Fe, 30; Cu, 5 and I, 1.05.

and high ME diets with the same CP level in equal proportions gave an intermediate ME level (2,850 kcal/kg). Blending low and high CP with the same ME level in proportion of 3 : 0, 2 : 1, 1 : 2 and 0 : 3 gave 85, 95, 105 and 115% of NRC requirement diets. Fish meal and soybean meal (1 : 1) were used as major protein sources. Experimental diets were put in the troughs at 9 : 00 a.m. daily from weighed containers. Feed consumption was recorded every three weeks. Egg production and mortality were recorded daily and egg were weighed weekly. Body weights were recorded at 150, 192

Table 2. Record of performance of laying hens fed diets with 4 levels

Ratio to NRC (%)	85			95			105	
ME (kcal/kg)	2700	2850	3000	2700	2850	3000	2700	2850
1. Number of hens died or removed								
	3	3	4	2	2	3	1	2
2. Initial body weight on 150 days (g)								
	1123	1119	1126	1131	1124	1127	1133	1126
3. Body weight gain (g)								
150-192 days	455	448	451	468	469	458	460^{ab}	472^{b}
192-255	127^{a}	136^{ab}	146^{b}	119^{a}	123^{a}	149^{b}	124^{a}	138^{b}
4. Egg production rate (%)								
150-171 days	13.9	14.4	13.3	13.3	14.0	13.3	13.1	12.5
-192	62.0^{a}	67.0^{b}	65.2^{b}	66.1	67.4	65.8	70.2	69.7
-213	82.0^{a}	79.6^{ab}	78.5^{b}	84.9	83.6	82.5	87.0	86.2
-234	85.2^{a}	83.1^{b}	81.6^{c}	89.4	87.8	87.0	92.4	91.5
-255	86.2	86.0	85.6	89.7	89.0	88.4	91.6	90.4
150-192	38.0	40.7	39.3	39.7	40.7	39.6	41.7	41.1
192-255	84.5^{a}	82.9^{ab}	81.9^{b}	88.0^{a}	86.8^{b}	85.7^{b}	90.3^{a}	88.2^{b}
150-255	65.9	66.0	64.8	68.7	68.4	67.4	70.9	70.1
5. Egg mass (g/hen/day)								
150-171 days	6.6	7.2	6.7	6.4	6.9	6.6	6.3	6.1
-192	34.8^{a}	37.3^{b}	36.4^{b}	37.2	37.9	37.0	39.5	39.7
-213	48.3^{a}	46.9^{b}	46.4^{b}	50.2	50.1	49.0	51.6	52.5
-234	50.9	50.1	49.9	54.4	54.3	54.1	57.5	58.0
-255	54.0	53.5	54.0	56.2	55.8	55.7	57.3	57.1
150-192	20.7^{a}	22.3^{b}	21.6^{ab}	21.8	22.4	21.8	22.9	22.9
192-255	51.1	50.2	50.1	53.6	53.4	52.9	55.5	55.9
150-255	38.9	39.0	38.7	40.9	41.0	40.5	42.4	42.7
6. Feed intake (g/hen/day)								
150-171 days	94.0^{a}	93.3^{a}	84.5^{b}	94.3^{a}	90.8^{b}	88.3^{b}	92.6	90.7
-192	101.5^{a}	100.8^{a}	93.0^{b}	98.4^{a}	96.5^{a}	93.1^{b}	96.1	95.7
-213	108.8^{a}	104.1^{b}	100.2^{c}	107.7^{a}	104.8^{ab}	101.5^{b}	106.8	105.6
-234	116.2^{a}	110.8^{b}	110.4^{b}	116.3^{a}	112.9^{b}	112.3^{b}	116.6	115.6
-255	119.3^{a}	120.7^{a}	116.4^{b}	118.4	119.6	116.7	119.1	117.4
150-192	97.8	97.1	88.8	96.4^{a}	93.7^{ab}	90.7^{b}	94.4	93.2
192-255	114.8^{a}	111.9^{ab}	109.0^{b}	114.1^{a}	112.4^{ab}	110.2^{b}	114.2	112.9
150-255	108.0^{a}	106.0^{a}	100.9^{b}	107.0^{a}	104.9^{ab}	102.4^{b}	106.2	105.0
7. Feed conversion ratio								
150-171 days	14.2	13.0	12.6	14.7	13.2	13.4	14.7	14.9
-192	2.92	2.70	2.55	2.65	2.55	2.52	2.43	2.41
-213	2.25	2.22	2.16	2.15	2.09	2.07	2.07	2.01
-234	2.28	2.21	2.21	2.14	2.08	2.08	2.03	1.99
-255	2.21	2.26	2.16	2.11	2.14	2.10	2.08	2.06
150-192	8.56	7.86	7.58	8.68	7.88	7.96	8.57	8.66
192-255	2.25	2.23	2.17	2.13	2.10	2.08	2.06	2.02
8. Egg weight (g)								
150-171 days	47.5	50.0	50.4	48.1	49.3	49.8	48.1	48.8
-192	56.1	55.7	55.8	56.3	56.2	56.2	56.3	57.0
-213	58.9	58.9	59.1	59.1	59.9	59.4	59.3	60.9
-234	59.7	62.9	61.2	60.9	61.8	62.2	62.2	63.4
-255	62.6	62.2	63.1	62.7	62.7	63.0	62.5	63.2
150-192	54.5	54.8	55.0	54.9	55.0	55.1	54.9	55.7
192-255	60.5	60.6	61.2	60.9	61.5	61.7	61.5	63.4

Each value except feed intake and feed conversion ratio is mean of 60 hens.

Values of feed intake and feed conversion are means of 3 feed troughs.

Means within the same row with different letters differ significantly ($P<0.05$).

of crude protein and 3 level of ME for 150 to 255 days

	115			85	95	105	115			
3000	2700	2850	3000					2700	2850	3000
2	1	1	2	10	7	5	4	7	8	11
1149	1121	1145	1114	1123	1127	1136	1127	1127	1129	1129
451^{a}	473^{a}	493^{ab}	508^{b}	451^{a}	465^{ab}	461^{a}	491^{b}	464^{a}	471^{ab}	476^{b}
148^{b}	126^{a}	133^{ab}	144^{b}	136	130	137	134	124^{a}	133^{ab}	147^{b}
13.1	13.1	13.7	12.6	13.9	13.5	12.9	13.1	13.4	13.7	13.1
70.0	72.0	71.8	71.8	64.7^{a}	66.4^{a}	70.0^{b}	71.9^{b}	67.6	69.0	68.2
85.0	89.8	89.0	88.5	80.0^{a}	83.7^{b}	86.1^{c}	89.1^{d}	85.9^{a}	83.1^{b}	83.6^{b}
90.4	92.8	92.1	91.9	83.3^{a}	88.1^{bc}	91.4^{c}	92.3^{c}	90.0^{a}	88.6^{b}	87.7^{c}
89.8	91.7	90.4	89.6	85.9^{a}	89.0^{b}	90.6^{b}	90.6^{b}	89.8	89.0	88.4
41.6	42.6	42.8	42.2	39.3^{a}	40.0^{a}	41.5^{ab}	42.5^{b}	40.5	41.4	40.7
88.4^{b}	91.4	90.5	90.0	83.1^{a}	86.9^{b}	89.4^{c}	90.7^{c}	85.3	86.9	86.6
69.7	71.9	71.4	70.9	65.6^{a}	68.1^{b}	70.2^{bc}	71.4^{c}	69.3	68.7	68.2
6.4	6.6	6.9	6.3	6.8^{a}	6.6^{a}	6.3^{b}	6.6^{a}	6.5	6.8	6.5
39.7	41.1	41.1	40.8	36.2^{a}	37.4^{ab}	39.6^{bc}	41.0^{c}	38.2	39.0	38.5
51.3	54.3	54.0	53.2	47.2^{a}	49.8^{b}	51.8^{c}	53.8^{d}	51.1	50.9	50.0
57.0	58.8	58.2	57.5	50.3^{a}	54.3^{b}	57.5^{c}	58.2^{c}	55.4	55.2	54.6
56.6	58.2	57.0	56.0	53.8^{a}	55.9^{b}	57.0^{b}	57.1^{b}	56.4	55.9	55.6
23.1	23.9	24.0	23.6	21.5^{a}	22.0^{a}	23.0^{ab}	23.9^{b}	22.3	22.9	22.5
54.7	57.1^{a}	56.4^{ab}	55.6^{b}	50.5^{a}	53.3^{bc}	55.4^{cd}	56.4^{d}	54.3	54.0	53.3
42.2	43.8	43.4	42.8	38.9^{a}	40.8^{ab}	42.4^{bc}	43.3^{c}	41.5	41.5	41.1
90.1	91.5^{a}	88.6^{ab}	86.7^{b}	90.6	91.1	91.1	89.0	93.1^{a}	90.9^{ab}	87.5^{b}
93.8	96.8^{a}	95.3^{a}	91.5^{b}	98.4^{a}	96.0^{a}	95.2^{a}	89.0^{b}	98.2^{a}	97.1^{a}	92.9^{b}
104.6	110.9^{a}	105.5^{b}	104.2^{b}	104.4	104.7	105.7	106.9	108.6^{a}	105.0^{ab}	102.6^{b}
114.9	118.4^{a}	115.1^{ab}	112.3^{b}	112.5	113.8	115.7	115.3	116.9^{a}	113.6^{ab}	112.5^{b}
117.3	120.4^{a}	116.2^{ab}	114.6^{b}	118.8	118.2	117.9	117.1	119.3	118.5	116.3
92.0	94.2	92.0	89.2	94.5	93.6	93.2	89.0	95.7^{a}	94.0^{ab}	90.2^{b}
112.3	116.6^{a}	112.3^{ab}	110.4^{b}	111.9	112.2	113.1	113.1	114.9^{a}	112.4^{ab}	110.5^{b}
104.1	107.6^{a}	104.1^{ab}	101.9^{b}	104.9	104.8	105.1	103.5	107.2^{a}	105.0^{ab}	102.4^{b}
14.1	13.9	12.8	13.8	13.3	13.4	14.6	13.5	14.4	13.5	13.5
2.36	2.36	2.41	2.36	2.72	2.57	2.40	2.38	2.59	2.52	2.45
2.07	2.04	1.95	1.96	2.21^{a}	2.10^{ab}	2.05^{b}	1.98^{bc}	2.13	2.07	2.07
2.02	2.01	1.98	1.95	2.23^{a}	2.10^{ab}	2.03^{b}	1.98^{bc}	2.12	2.07	2.07
2.07	2.07	2.04	2.05	2.21^{a}	2.12^{ab}	2.07^{bc}	2.05^{c}	2.12	2.13	2.10
8.23	8.13	7.61	8.08	8.01	7.99	3.50	7.94	8.50	8.01	7.98
2.05	2.04	1.99	1.99	2.22^{a}	2.11^{ab}	2.05^{b}	2.00^{bc}	2.12	2.09	2.08
48.9	50.4	50.4	50.0	48.7	49.1	48.6	50.3	48.5	49.6	49.6
56.7	57.1	57.2	56.8	55.9	56.2	56.7	57.0	56.5	56.5	56.5
60.4	60.5	60.7	60.1	59.0	59.5	60.2	60.4	59.5	61.3	59.8
63.1	63.4	63.2	62.6	61.4	61.3	62.9	63.1	61.6	62.3	62.2
63.0	63.5	63.1	62.5	62.6	62.8	62.9	63.0	62.8	62.8	62.9
55.5	56.1	56.1	55.9	54.8^{a}	55.0^{ab}	55.4^{ab}	56.0^{b}	55.1	55.3	55.3
61.9	62.5	62.3	61.8	60.8^{a}	61.4^{ab}	62.3^{b}	62.2^{b}	61.4	62.1	61.5

and 255 days of age.

3. *Analysis of the data*

The general linear models procedure (SAS Institute Inc. 1985) was used for the analysis of data. The calculated response surface was conducted by a following equation : $\hat{Y} = b_0 + b_1x_1 + b_2x_2 + b_3x_1^2 + b_4x_2^2 + b_5x_1x_2$
Where $\hat{Y}$ represents the egg production rate, egg size, egg mass, weight gain, feed consumption or feed conversion ratio, x_1 is amino acids ratio to the NRC recommendations and x_2 is ME contents (kcal/kg).

Results

Performance for four protein levels in combination with three energy levels are presented in Table 2. Egg production commences at about 150 days of age, rises sharply and reaches a peak at about 210–230 days of age. The production cycle may be conveniently divided into two stages (popularly called phases).

1. *Livability*

The number of mortality is presented in Table 2. Livability was very good for all dietary treatment groups during the entire experiment and there was no significant differences between the treatments. However, there were weak trends that the livability would decrease with increasing CP levels and would increase with increasing ME levels.

2. *Body weight gain*

More than 450 g of body weight gain was observed for 6 weeks from 150 to 192 days of age. The weight gain increased significantly with increasing ME levels (Table 2). The weight gain would increase with increasing CP levels only when hens were fed the highest CP diet (Table 2). The body weight gain was less than 150 g for 9 weeks from 192 to 255 days, but it increased significantly with increasing ME levels regardless of CP levels. Dietary CP level had no effect on body weight gain during this periods (Table 2).

3. *Egg production rate*

Egg production rate and feed consumption were calculated on a hen-day basis. All hens started to lay between 150 to 171 days of age and egg production rate from all treatment groups exceeded 50% by 192 days of age. Both dietary CP and ME levels had no effect on the day of first egg and the age to reach 50% egg production rate. Throughout the whole experimental periods, egg production increased with increasing CP levels (Table 2 ; Figs. 1, 2, 3 and 4). The egg production rate was not affected by ME level till 192 days of age (Fig. 1), but it tended to decrease with increasing ME level after that age (Figs. 2, 3 and 4). The low energy diet had little effect on egg output in terms of numbers and weights, but significantly increased feed intake. The birds fed low energy diet had responded by increasing feed consumption.

Maximum egg production occurred between 213 and 234 days of age for birds fed 105 and 115% of NRC requirement diets, but for birds fed the 85 and 95% NRC requirement diets egg production continued to increase after that age (Table 2).

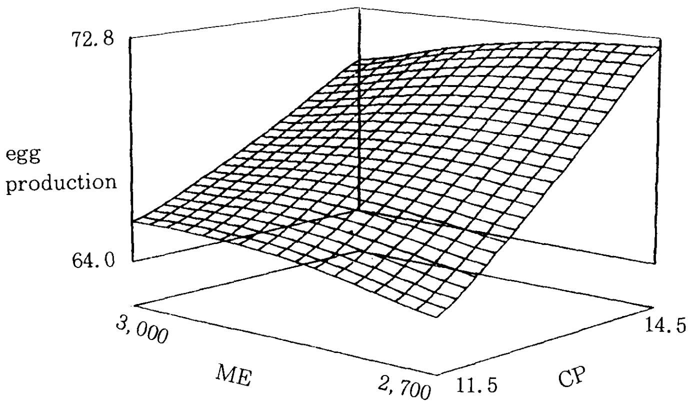

Fig. 1. Response surfaces depicting the relationship between egg production from 172 to 192 days of age and dietary crude protein and metabolizable energy levels

		S.E.
B_0	−256.03	(256.47)
B_1	115.11	(104.04)
B_2	180.56	(174.96)
B_3	12.58	(36.1)
B_4	−24.69	(30.74)
B_5	−41.13	(26.23)

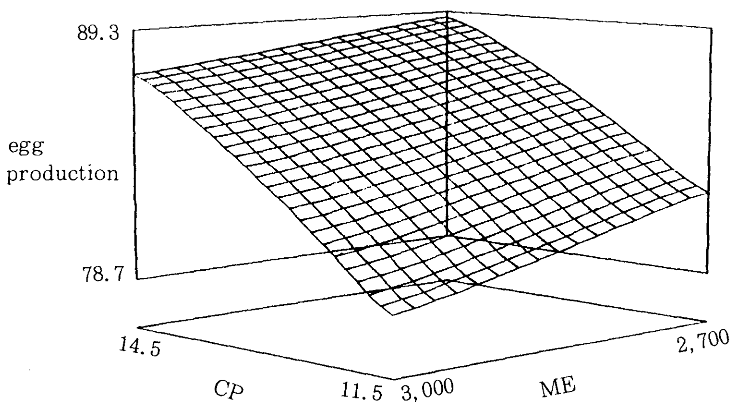

Fig. 2. Response surfaces depicting the relationship between egg production from 193 to 213 days of age and dietary crude protein and metabolizable energy levels

		S.E.
B_0	130.02	(185.45)
B_1	23.90	(75.23)
B_2	−40.96	(126.51)
B_3	−25.69	(26.10)
B_4	2.36	(22.23)
B_5	19.04	(18.97)

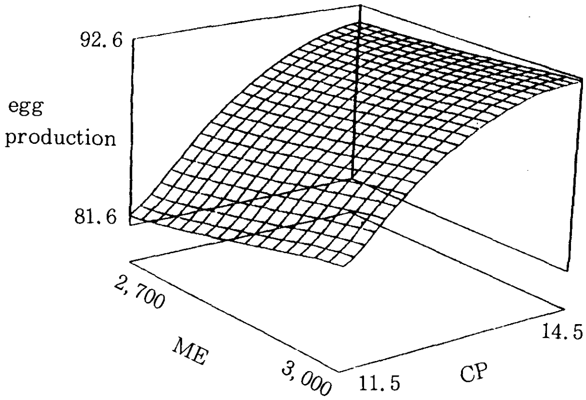

Fig. 3. Response surfaces depicting the relationship between egg production from 214 to 234 days of age and dietary crude protein and metabolizable energy levels

		S.E.
B_0	98.07	(206.25)
B_1	150.94	(83.70)
B_2	−61.89	(140.70)
B_3	−98.14	(29.03)
B_4	5.0	(24.7)
B_5	26.2	(21.09)

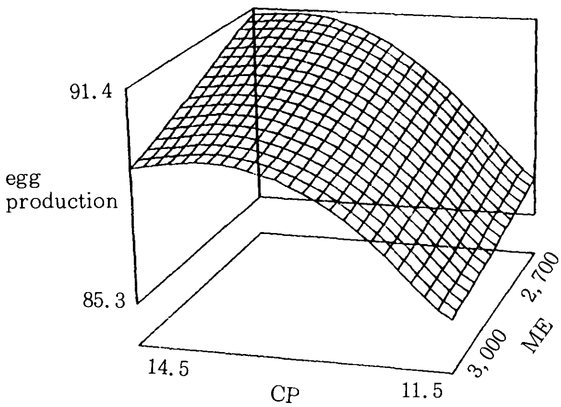

Fig. 4. Response surfaces depicting the relationship between egg production from 235 to 255 days of age and dietary crude protein and metabolizable energy levels

		S.E.
B_0	−14.05	(249.02)
B_1	222.08	(101.01)
B_2	−4.94	(169.88)
B_3	−82.36	(35.05)
B_4	2.54	(29.85)
B_5	−14.89	(25.47)

4. Egg weight

As shown in Table 2, egg weight increased with age on all diets. Egg weight increased with increasing CP level until 255 days of age (Table 2 ; Figs. 5 and 6). ME level was without significant effect on egg weight throughout all experimental periods (Table 2 ; Figs. 5 and 6).

5. Egg mass

Egg mass is calculated as egg weight × egg production rate. Since egg weight increased with age on all diets and egg production rate increased with increasing CP levels, egg mass also increased with age and by CP levels in the similar way as egg weight and production rate. Egg mass was not affected by ME level throughout the whole experimental diet (Table 2).

6. Feed consumption

Feed intake increased with age. It was not affected by dietary CP levels, but decreased with increasing ME levels.

7. ME intake

Increasing the dietary energy level decreased feed intake. However, energy intake per hen per day was increased as dietary energy increased (Table 3).

8. CP intake

As protein level of the diets increased, protein intake per hen per day also increased (Table 4).

9. Feed conversion ratio (kg feed/kg egg)

As protein level increased, hen-day egg production and egg weight increased and

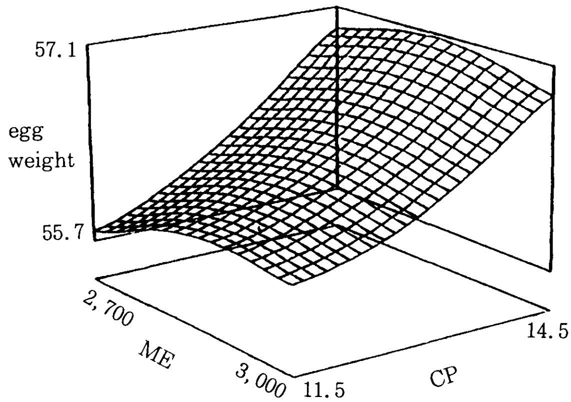

Fig. 5. Response surfaces depicting the relationship between egg size from 172 to 192 days of age and dietary crude protein and metabolizable energy levels

		S.E.
B_0	−2.76	(100.83)
B_1	−24.63	(48.80)
B_2	49.27	(64.50)
B_3	8.16	(13.90)
B_4	−9.49	(10.94)
B_5	4.36	(11.67)

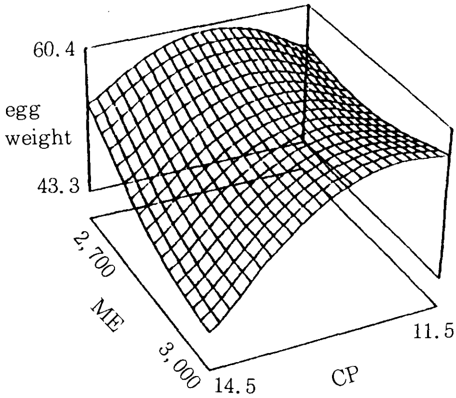

Fig. 6. Response surfaces depicting the relationship between egg size from 193 to 213 days of age and dietary crude protein and metabolizable energy levels

		S.E.
B_0	314.40	(1382.5)
B_1	1092.65	(669.05)
B_2	−536.48	(884.53)
B_3	−310.38	(190.58)
B_4	122.26	(150.00)
B_5	−176.25	(159.97)

Table 3. Metabolizable energy intake of laying hens (kcal/hen/day) as influenced by energy levels in the diets (kcal/kg diet)

Days of age	Dietary ME		
	2,700	2,850	3,000
150 - 192	258	268	271
192 - 255	310	320	332
150 - 255	289	299	307

Table 4. Protein intake of laying hens as influenced by protein levels in the diets

Days of age	Ratio to NRC			
	85% (11.5%)	95% (12.5%)	105% (13.5%)	115% (14.5%)
	g/hen/day			
150 - 192	11.6	12.9	14.2	14.8
192 - 255	13.8	15.5	17.2	18.8
150 - 255	12.9	14.4	16.0	17.3

The figures in parentheses represent crude protein content of the diet.

consequently the amount of feed required to produce a unit of eggs decreased. Increasing the dietary protein levels decreased feed conversion ratio significantly. Increasing the dietary energy levels decreased feed intake and consequently decreased feed conversion ratio (Table 2).

Discussion

Recently PESTI (1991) reported the regression analysis result on the relationship between changes in CP and ME levels in the diets and the performance of laying hens. The range of CP and ME levels employed ranged from 12.0 to 22.4% and 2,600 to 3,200 kcal per kg diet, respectively. The CP and ME used in this study were 10.6 to 14.5% and 2,700 to 3,000 kcal per kg diet, respectively. Both studies showed similar trend, i.e., when the egg production rate exceeded 65%, egg production rate, egg mass and egg weight increased with increasing age and CP levels. The present study showed that the CP level which maximized hen performance was 14.5% or more across all ME levels, in contrast to about 18.0% CP at 3,000 kcal/kg ME calculated from the data of PESTI (1991) for hens at 196 to 252 days of age. In this experiment, methionine, lysine and tryptophan were adjusted at the requirement level of NRC. The ratio of the methionine level used by PESTI (1991) to the NRC value (in a diet containing 18.0% CP and 3,000 kcal/kg ME) was estimated to be 106%. Though the CP level was higher, the methionine level was lower than the level used in this experiment. It has been demonstrated that the CP requirement for optimum performance can be decreased by adding the limiting amino acid (BLAIR *et al.*, 1976 ; MARCH and BIELY, 1972 ; SCHUTTLE, 1987). The difference in the dietary CP requirement for optimum performance shown between the two above mentioned experiments showed that limiting amino acid level was a better criterion than CP level for diet formulation.

Pullets fed the 105% NRC diet during the laying peiod produced fewer and lighter-weight eggs than fed the 115% NRC diet. Also their body weight were significantly lighter than the 115% NRC diet groups. This information suggested that some of amino acids recommended by the NRC (1984) might not be adequate to support an optimum performance. The results of our experiments are generally consistent with reports by CALDERON and JENSEN (1990). These investigators reported that performance of laying hens fed 13 or 14% protein diets were inferior to those fed higher levels of protein, although birds on low-protein diets received all of the essential amino acids adequately. The reasons for suboptimal performance of laying hens fed low protein amino acid supplemented diets are not clear. It is well accepted that poultry do not have a specific need for protein per se. Animals need amino acids and the requirement is really an amino acid requirement. Consequently, the inferior performance is not likely due to inadequate protein intake. Several possibilities that exist are : (1) The requirement for certain essential amino acids as suggested by NRC (1984) might have been underestimated. Recently, JENSEN (1991) presented information suggesting the requirement for isolecuine and valine as recommended by NRC (1984) might not be adequate for laying hens. KESHAVARZ and JACKSON (1990) also suggested that the NRC (1984) suggested requirement for tryptophan and/or isoleucine might be inadequateate for laying hens.

(2) Several investigators have reported that the requirement for certain essential amino acids for laying hens increase with an increase in the dietery level of protein (CARDERON and JENSEN, 1990 ; MENDONCA and JENSEN, 1989 ; JENSEN *et al.*, 1990 ; MORRIS *et al.*, 1987). In many experiments concerning the use of low protein diets, while the protein level was reduced, the essential amino acids were maintained to meet or exceed the NRC recommendations. The interaction among extra levels of essential amino acids with low protein diets might also be a contributing factor for the failure of low-protein essential amino acid-adequate diets to support an optimum performance.

(3) The amount of non-essential nitrogen in the diets containing adequate essential amino acids has not been well established. Conceivably, when the non-essential nitrogen content of a diet is limiting, the conversion of essential to non-essential amino acids might reduce the level of essential amino acids on the diet to the extent that they become limiting for optimum performance.

(4) It has been reported that the retio of essential to non-essential nitrogen in the feed is an important factor for optimum utilization of amino acids. When the dietary level of protein is reduced but the essential amino acids are maintained, the ratio of essential to non-essential nitrogen might become suboptimal for supporting optimum performance.

The aforementioned points need further clarification for successful implementation of low protein amino acid supplemented diets in commercial practices.

With increasing ME levels, the egg production rate and egg mass tended to decrease across all CP levels throughout the whole experiment. Egg weight was not affected by ME levels.

Studies on the effects of dietary energy per se on hen performance are confusing and contradictory. In many of these studies the ratio between dietary energy and protein or nutrient density varied as energy level changed. Since food intake is controlled primarily by energy needs, intakes of protein and other nutrient also varied in these studies (CAREW *et al.*, 1976 ; GROVER *et al.*, 1972) and confounded the results. However, in studies where the proportion of dietary energy to protein was held constant, increase in dietary energy usually did not affect hen performance (DAVIS *et al.*, 1958 ; MACLYNTYRE *et al.*, 1957 ; MARCH and BIELY, 1963 ; TOUCHBURN and NABER, 1962 ; TURK *et al.*, 1958). GROVER *et al.* (1972) observed a similar depression in egg production with increasing dietary energy (2,840 to 3,060 kcal/kg) when dietary energy-protein ratio varied. GLEAVES *et al.*, (1968) proposed that high energy diets depressed egg production because feed intake and hence protein intake were reduced. Our results showed that a similar effect ocurred when the energy protein ratio was not held constant, although it ocurred at a high dietary energy level (3,000 kcal/kg).

It appeared that young laying hen was most sensitive to dietary protein level, whereas energy levels affected little during reaching a peak at about 150-255 days of age (Table 2). Many factors may influence feed consumption and protein requirements in laying hens. Among these are environmental temperature, stage of production and energy content of the diet. Present experiment on the protein requirements of laying hens indicated that for maximum production of about 90% and maximum egg size, hens required about 18 grams of protein per day (Table 4).

The daily energy requirement of hens for maximum production of about 90% ranged from approximately 310 to 330 kcal ME per day under moderate environmental temperature (Table 3). Cost per unit weight was found to be minimal with the diet of 2,700 kcal ME/kg, but increasing the dietary energy levels increased feed efficiency. DE GROOTE (1972) did a marginal income and cost analysis of the effect of nutrient density on egg production. He concluded that energy levels corresponding to those with minimum feed costs were not same as those that maximized profits. Present experiment have suggested that in a moderate environmental temperature (from 15° to 25°C) metabolizable energy levels of 2,700–2,850 kcal per kg might give economical results.

The body weight gain ranged from 448 to 508 g for 150 to 192 days of age and from 119 to 149 g for 192 to 255 days of age. In birds fed the 2,700 kcal/kg ME diet, weight gain reached a plateau at 105% of NRC requirement but the weight gain continued to increase with increasing CP levels in the hens fed the 2,850 and 3,000 kcal/kg ME diets. The result indicated that higher CP level was necessary to achieve maximum body weight gain for 150 to 192 days of age. At the later period, the dietary CP level had no effect on the body weight gain. However, at all CP levels body weight gain increased with increasing ME levels.

Feed intake increased with age and decreased with dietary ME levels but was not affected by dietary CP levels. During the period between 150 to 192 days of age, feed intake decreased from 95.7 g for hens fed the 2,700 kcal/kg diet to 90.2 g for hens fed the 3,000 kcal/kg diet. The ME intake, however, increased from 258 to 271 kcal/hen/day. Between 192 and 255 days of age, feed intake decreased from 114.9 g to 110.5 g and energy intake increased from 310 to 332 kcal/hen/day for hens fed 2,700 and 3,000 kcal/kg diet, respectively. This difference in energy intake might reflect on body weight gain observed in the present study. MORRIS (1968) concluded that although pullets offered different diet tended to adjust consumption to maintain the same calorie intake, this adjustment was imperfect. Thus the birds fed a high energy diets usually over-consumed calories and gained more weight than birds fed a lower energy diets. Since the degree of overconsumption was strain-related, diets for certain strain of hens can be formulated to contain lower energy to more effectively control the body weight of laying hens.

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飼料中の粗タンパク質および代謝エネルギー水準が若雌鶏の産卵成績におよぼす影響

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産卵鶏における必須アミノ酸の要求量を決定するに先立って，若雌鶏の産卵開始から最高産卵に達するまでの最適な粗タンパク質（CP）と代謝エネルギー（ME）の水準を明らかにするために，メチオニン，リジンおよびトリプトファンが NRC 要求量の 85%，95%，105%，115%，そして ME 水準が 2,700，2,850，3,000 kcal/kg の合計 12 種類の飼料を，1 飼料当り 60 羽の鶏にそれぞれ給与して産卵試験を行った。試験は開放鶏舎で試験期間中の平均気温は 15℃ から 25℃ の間であった。その結果，飼料消費量は ME 水準が高くなるほど少なく摂取する傾向にあったが，CP 水準による差は認められなかった。各産卵ステージの 1 日 1 羽当り ME 摂取量は，飼料の ME 水準が高いほど多く摂取する傾向にあった。各産卵ステージの 1 日 1 羽あたり CP 摂取量は，CP 水準が高いほど多かった。産卵率は，CP 水準が高くなるほど優れる傾向にあった。ME 水準による影響は 192 日齢までは認められなかったが，それ以降は ME 水準が高くなると低下する傾向にあった。産卵日量は，CP 水準が高くなるほど優れる傾向にあった。しかし ME 水準との間に一定の傾向は認められなかった。平均卵重は，CP 水準が高くなるほど重くなった。しかし ME 水準との間に一定の傾向は認められなかった。飼料効率は，CP と ME 水準が高いほど優れる傾向にあった。本実験条件下における鶏卵生産には，ME 2,700-2,850 kcal/kg が経済的によいと考えられた。産卵率が約 90% の最高産卵時には，1 日 1 羽当たり 310-330 kcal の ME を摂取した。CP の要求量は 14.5% か，それ以上であった。最高の産卵と卵重に達するためには，1 日 1 羽当たり蛋白質を 18 g 摂取した。

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