# METABOLISM AND NUTRITION

# Effects of feeding regimen, fiber inclusion, and crude protein content of the diet on performance and egg quality and hatchability of eggs of broiler breeder hens

M. Mohiti-Asli,*[1] M. Shivazad,* M. Zaghari,* M. Rezaian,† S. Aminzadeh,‡ and G. G. Mateos§

*Department of Animal Science, University College of Agriculture and Natural Resources, University of Tehran, 31587-11167 Karaj, Iran; †Department of Basic Science, Faculty of Veterinary Medicine, University of Tehran, 14155-6453 Tehran, Iran; ‡Department of Animal and Marine Biotechnology, National Institute of Genetic Engineering and Biotechnology, 14965-161 Tehran, Iran; and §Department of Animal Science, Universidad Politécnica de Madrid, 28040 Madrid, Spain

**ABSTRACT** A 12-wk experiment was conducted to study the effects of feeding regimen, inclusion of a fiber source, and CP content of the diet on performance of broiler breeder hens. In total, 360 hens and 60 males, 43 wk of age, were assigned to 60 floor pens (6 hens and 1 male each). There were 12 treatments arranged factorially with 2 feeding regimens [restricted (R) and liberal feeding (close to ad libitum consumption; LIB)], 3 sources of fiber (0, 3% inulin, and 3% cellulose), and 2 levels of CP (14.5 and 17.4%). No interactions among main effects were observed for any of the traits studied, and therefore, only main effects are presented. Body weight, liver weight, and abdominal fat weight were higher ($P < 0.001$) for the LIB than for the R-fed hens. However, egg production ($P < 0.001$), fertility index ($P < 0.05$), and percentage of hatch ($P < 0.01$) were lower for LIB than for R hens. The weights of ovaries ($P < 0.05$) and the size of the first preovulatory follicle ($P < 0.05$) were higher for the LIB than for the R hens. Also, egg yolk, egg weight, and BW of the hatching chicks were higher ($P < 0.001$) for the LIB hens. The inclusion of a fiber source in the diet decreased ($P < 0.05$) feed intake, BW gain, absolute liver and abdominal fat weight, and egg yolk weight, with effects being more pronounced ($P < 0.05$) with cellulose than with inulin. Hens fed additional fiber produced more ($P < 0.05$) eggs that were more fertile ($P < 0.05$) than control hens. Crude protein content of the diet did not affect hen performance but reduced ($P < 0.01$) the relative weight of the liver, ovary, and abdominal fat. It is concluded that the inclusion of inulin or cellulose in the diet improved hen performance and that an increase in dietary CP reduced obesity in broiler breeder hens.

**Key words:** broiler breeder hen, cellulose, crude protein, feeding regimen, inulin

2012 Poultry Science 91:3097–3106
http://dx.doi.org/10.3382/ps.2012-02282

## INTRODUCTION

An excess of energy intake results in increased BW and obesity in broiler breeder hens with higher incidence of fatty livers and poor reproductive performance (Robinson et al., 1993). Obesity is often linked to changes in lipid metabolism, with accumulation of triglyceride (**TG**) in the liver and the ovary. Consequently, an excess of energy intake increases the incidence of ovarian dysfunction, follicular dystrophy, and the concentration of lipids in plasma with adverse effects on broiler breeder performance, with special relevance immediately after peak of egg production (Chen et al., 2006). Feed restriction is a common practice to control obesity in broiler breeders. Restricted (**R**) feeding improves shell quality and reproductive efficiency, as compared with more liberal and close to ad libitum (**LIB**) feeding, resulting in a higher number of settable eggs, less incidence of erratic oviposition and number of double-yolked eggs, and an increase of fertility and hatchability (Yu et al., 1992; Hocking, 1993; Robinson et al., 1993). However, feed restriction is a practice under general scrutiny because of its negative impact on poultry welfare (Hocking et al., 2001).

Data on the effects of fiber on reproductive performance and lipid metabolism in broiler breeder hens are scarce. Dietary fiber decreases hepatic lipogenesis and reduces obesity in humans and rats (Delzenne, 1999). Enting et al. (2007) studied the effects of inclusion of fibrous ingredients on broiler breeder hen performance. In this report, high amounts of dietary fiber were used which resulted in low-density diets. Inulin is a soluble


Received March 6, 2012.
Accepted September 8, 2012.
[1]Corresponding author: mmohiti@ut.ac.ir

dietary fiber extracted from chicory roots, which have shown promise as a regulator of glucose metabolism and obesity in some animal species (Delzenne, 1999). Few reports are available on the effects of dietary cellulose on hepatic lipogenesis in chicks, and in fact, the authors have not found any research conducted with broiler breeders. In growing chicks, Akiba and Matsumoto (1977) reported that the inclusion of cellulose in the diet depressed lipid accumulation in the liver.

An increase in CP content of the diet depressed fatty acid synthesis in the liver (Masoro et al., 1950) and adipose tissue (Leveille, 1967) of rats and in the liver of chicks (Rosebrough et al., 2002). However, the effects of dietary CP on lipogenesis have not been extensively studied in broiler breeder hens. The hypothesis of the research was that the inclusion of a fiber source and the increase in CP content of the diet could reduce obesity and obesity-related problems and improve reproductive performance in broiler breeder hens and that the effects could be more pronounced in LIB than in R-fed birds. The objectives of the study were to study the effects of feeding regimen, inclusion of additional fiber, and level of CP of the diet on reproductive performance of broiler breeder hens from 43 to 55 wk of age.

## MATERIALS AND METHODS

### Birds and Husbandry

All experimental procedures were approved by the Animal Care and Welfare Committee of University of Tehran. In total, 360 hens and 60 males broiler breeders (Ross 308) with similar BW were selected at 41 wk of age from a commercial flock and kept in a controlled environmental barn at 22 ± 2°C under a lighting program consisting in 14.5 h of light and 9.5 h of dark. Birds were wing tagged and randomly assigned into 60 floor pens (1.25 m × 2.50 m) bedded with wood shavings and provided with a nest, a linear trough feeder with a 42-mm grill for the females, a pan feeder for the males, and an automatic bell waterer. The design of the grills prevented males from consuming the feed of the hens. Males and females were penned together from the beginning of the experiment.

### Diets, Ingredients, and Experimental Design

Before the start of the experiment, all hens were fed for 2 wk a common breeder diet with 2,800 kcal of $AME_n$/kg and 14.5% CP and egg production and BW were controlled by pen. Then they were fed corn-soybean meal mash diets that contained 2,800 kcal of $AME_n$/kg, 3.0% Ca, and 0.35% available P (Table 1). The low CP diet of the hens contained 0.65% Lys, whereas the high CP diet contained 0.78% Lys. The remaining indispensible AA were formulated related to Lys content according to the ideal protein concept as indicated by the Ross Breeder Manual (2007). Fat was not added to any diet because the presence of lipids might decrease hepatic fat synthesis in chicks (Tanaka et al., 1983). The diets with the higher CP content included higher amounts of corn gluten meal in substitution primarily of corn. Commercial sources of inulin (Orafti IPS, Beneo Animal Nutrition, Tienen, Belgium) and cellulose (Arbocel FD00, J. Rettenmaier & Söhne GmbH & Co., Rosenberg, Germany) were included at 3% in the diet at the expense (wt:wt) of double-washed sand. The inulin used contained more than 90% fructans [glucosyl-(fructosyl)$_n$ with an average degree of polymerization of 10 and a range between 2 and 60] with the remaining 10% being a mixture of glucose, fructose, and sucrose. The cellulose source used contained 90% cellulose with an average fiber length of 150 μm, a thickness of 35 μm, a bulk density of 150 to 180 g/L, and a pH of 7.5 per supplier information. The experimental diets were fed once a day (0615 h). The R-fed hens received 160 g of feed/d from 43 to 45 wk of age and then feed allocation was gradually reduced to 154 g/d to 55 wk of age (Ross Breeders Manual, 2007). The hens fed LIB had free access to feed and had a voluntary feed intake 30% higher than that of the R hens (208 g/d). Males were fed 140 g/d of a diet based on corn, wheat bran, and soybean meal that contained 2,760 kcal of AME/kg, 12.7% CP, 5.5% Lys, and 1.2% Ca thought the trial, irrespective of the feeding regimen of the females. The experiment was conducted as a completely randomized design with 12 treatments arranged factorially with 2 feeding regimens (R vs. LIB), 3 fiber sources (0, 3% inulin, and 3% cellulose), and 2 levels of CP (14.5 and 17.4%). Each treatment was replicated 5 times, and the experimental unit was a pen with 6 hens and 1 male.

### Laboratory Analyses, Sample Collection, and Measurements

Representative samples of the diets were ground to pass through a 0.5-mm screen. The DM was analyzed by oven-drying at 110°C for 24 h (method 930.15) and CP by Kjeldahl method (method 984.13; AOAC, 2006). During the 12-wk study, feed consumption was controlled weekly by replicate. Eggs were collected daily and the weight of all the eggs produced by replicate was determined. In addition, hens were weighed individually before feed distribution every 2 wk. From these data, hen-day egg production, egg weight, egg mass, feed intake, FCR, and BW change were calculated.

The numbers of settable and defective eggs (soft-shell, shell-less, cracked, and double-yolked eggs) were recorded daily by replicate. In addition, at 48 and 54 wk of age, all the eggs produced during that week were collected and incubated in a commercial hatchery to determine fertility and hatchability indexes. At the end of the incubation period, the number of live chicks was counted and all chicks born alive were weighed per replicate. Unhatched eggs were examined by a trained hatchery technician, and the percentage of fertility and stage of embryonic mortality were determined.

**Table 1.** Ingredient composition and calculated nutrient content of the diets (g/kg unless otherwise indicated, as-fed basis)

| Item | Female diet | | Male diet |
|---|---|---|---|
| | 14.5% CP | 17.4% CP | |
| Ingredient | | | |
| Yellow corn | 693.19 | 635.52 | 695.13 |
| Soybean meal, 42.6% CP | 138.75 | 153.49 | 109.14 |
| Corn gluten meal, 62% CP | 43.95 | 86.19 | — |
| Wheat bran | — | — | 150.00 |
| Calcium carbonate | 68.57 | 68.68 | 20.46 |
| Dicalcium phosphate | 14.76 | 14.45 | 15.45 |
| Sand[1] | 30.00 | 30.00 | — |
| Vitamin and mineral premixes[2] | 5.00 | 5.00 | 5.00 |
| Sodium bicarbonate | 2.36 | 2.38 | 2.85 |
| Sodium chloride | 2.05 | 2.04 | 1.96 |
| L-Lysine HCl, 78% | 0.86 | 1.66 | 0.001 |
| DL-Methionine, 99% | 0.51 | 0.59 | — |
| Calculated nutrient content | | | |
| AME (kcal/kg) | 2,800 | 2,800 | 2,760 |
| CP | 145 | 174 | 127 |
| Arg | 7.7 | 8.7 | 7.4 |
| Ile | 5.7 | 6.9 | 4.7 |
| Lys | 6.5 | 7.8 | 5.5 |
| Met | 3.2 | 3.9 | 2.2 |
| Met + Cys | 5.8 | 7.0 | 4.6 |
| Thr | 5.2 | 6.1 | 4.5 |
| Trp | 1.5 | 1.8 | 1.5 |
| Val | 6.7 | 8.1 | 5.8 |
| Crude fiber | 25.5 | 25.8 | 39.4 |
| Linoleic acid | 15.8 | 14.6 | 18.2 |
| Calcium | 30 | 30 | 12 |
| Available phosphorus | 3.5 | 3.5 | 4.0 |
| Sodium | 1.6 | 1.6 | 2.0 |
| Determined content | | | |
| DM | 887 | 889 | 892 |
| CP | 148 | 179 | 125 |

[1]Sand was substituted (wt:wt) by inulin or cellulose in the corresponding experimental diets.

[2]Supplied the following (kilogram of feed): vitamin A (*trans*-retinyl acetate), 11,000 IU; vitamin $D_3$ (cholecalciferol), 3,500 IU; vitamin E (all α-tocopherol acetate), 100 IU; vitamin $K_3$ (bisulfate menadione complex), 5 mg; vitamin $B_{12}$ (cyanocobalamin), 0.03 mg; riboflavin, 12 mg; nicotinic acid, 55 mg; pantothenic acid (D-Ca pantothenate), 15 mg; folic acid, 2 mg; pyridoxine (pyridoxine·HCl), 6 mg; thiamine (thiamine mononitrate), 3 mg; D-biotin, 0.3 mg; choline (choline chloride), 300 mg; copper ($CuSO_4{\cdot}5H_2O$), 10 mg; iodine (KI), 2 mg; iron ($FeSO_4{\cdot}7H_2O$), 50 mg; manganese ($MnSO_4{\cdot}H_2O$), 120 mg; zinc (ZnO), 100 mg; selenium ($Na_2SeO_3$), 0.3 mg per kilogram of feed.

At 45 and 55 wk of age, 1 and 2 birds per replicate, respectively, were weighed and then slaughtered by cervical dislocation. The liver, ovary, oviduct, and the abdominal fat pad were dissected and weighed, and the relative weight (% of BW) of these organs was calculated. After weighing the ovaries, the follicles were dissected and classified into 3 groups according to size as indicated by Gilbert et al. (1983): large yellow follicles (>8 mm), small yellow follicles (2 to 8 mm), and white follicles (2 to 5 mm). In addition, abnormal hierarchical follicles (i.e., atretic follicles and type 3 follicles) were also measured. In addition, the diameter of the largest (**F1**) and the second largest (**F2**) ovarian follicles of the hens were measured using a digital vernier caliper.

Egg quality was measured in 4 eggs per replicate chosen at random from eggs produced at 49 wk and at 55 wk of age. Eggshell breaking strength was measured with an egg shell force gauge (model-II, Robotmation Co. Ltd., Tokyo, Japan) and shell thickness with an ultrasonic thickness gauge (Echometer 1062, Robotmation Co. Ltd.). Albumen height, yolk color, and Haugh units were measured with an automatic egg multitester equipment (EMT-5200, Robotmation Co. Ltd.) as indicated by Pérez-Bonilla et al. (2011). Yolks were separated from the tester tray using a Teflon spoon, and the chalaza were removed with a spatula. Then the yolks were rolled on a blotting paper towel to remove adhering albumen and weighed. The individual shells were washed with tap water to remove adhering albumen, dried at room temperature for 24 h, and weighed. Albumen weight was obtained by subtracting the yolk and shell weights from egg weight.

## Statistical Analysis

Data were analyzed as a completely randomized design with treatments arranged as a 2 × 3 × 2 factorial, and the main effects (feeding regimen, source of fiber, and CP content) and their interactions were studied. Normal distribution of data was determined using the NORMAL option of the UNIVARIATE procedure and for homogeneity of variances for treatment means

**Table 2.** Effect of feeding regimen and diet on performance of broiler breeder hens from 43 to 55 wk of age

| Item | Egg production (%) | Egg weight (g) | Egg mass (g/d) | Feed intake (g/d) | Feed conversion ratio (g/g) | BW gain (g/d) |
|---|---|---|---|---|---|---|
| Feeding regimen | | | | | | |
| Restricted | 65.1 | 68.3 | 44.4 | 157 | 3.60 | 5.6 |
| Ad libitum | 54.6 | 70.6 | 38.4 | 189 | 5.26 | 11.4 |
| SEM[1] | 1.34 | 0.31 | 0.95 | 0.49 | 0.16 | 0.27 |
| Fiber source | | | | | | |
| Control | 56.9[b] | 69.9 | 39.8 | 174[a] | 4.73 | 8.6[a] |
| Inulin, 3% | 59.8[ab] | 69.2 | 41.2 | 173[a] | 4.36 | 7.8[ab] |
| Cellulose, 3% | 62.9[a] | 69.2 | 43.3 | 172[b] | 4.19 | 7.1[b] |
| SEM[2] | 1.65 | 0.39 | 1.22 | 0.60 | 0.20 | 0.34 |
| CP (%) | | | | | | |
| 14.5 | 59.2 | 69.3 | 40.8 | 174 | 4.57 | 7.4 |
| 17.4 | 60.5 | 69.6 | 42.0 | 173 | 4.28 | 8.3 |
| SEM[3] | 1.34 | 0.31 | 0.95 | 0.49 | 0.16 | 0.27 |
| Effect (*P*-value)[4] | | | | | | |
| Feeding regimen | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Fiber source | 0.047 | 0.295 | 0.131 | 0.010 | 0.159 | 0.004 |
| CP | 0.475 | 0.568 | 0.402 | 0.219 | 0.214 | 0.029 |

[a,b]Means with different superscript letter within a column are significantly different ($P < 0.05$).

[1]Standard error of means for feeding regimen effect (n = 30).

[2]Standard error of means for fiber source effect (n = 20).

[3]Standard error of means for CP effect (n = 30).

[4]The interactions among main effects were not significant ($P > 0.10$).

through the Levene's test using the HOVTEST option of the GLM procedure of SAS (SAS Institute, 2004). Data on egg quality, egg hatchability, organ weight, and ovarian morphology were determined and analyzed at 2 ages, with age as a new main factor. The experimental unit was the pen for all traits studied. Data were analyzed using the GLM procedure of SAS (SAS Institute, 2004). Differences among treatment means were tested using Tukey test at $P \leq 0.05$.

## RESULTS

### Reproductive Performance

The percentage of soft-shell, shell-less, cracked, and double-yolked eggs was low (0.8% as an average) and not related to dietary treatment (data not presented). No interactions among main effects were detected for any of the traits studied, and therefore, only main effects are presented. Also, no interactions between dietary treatment and age were detected, and therefore, only cumulative data are presented in tables. The LIB-fed hens had higher feed intake (189 vs. 157 g; $P < 0.001$) and BW gain (11.4 vs. 5.6 g/d; $P < 0.001$) and poorer FCR (5.26 vs. 3.60; $P < 0.001$) than R-fed hens (Table 2). Also, LIB-fed hens produced fewer (54.6 vs. 65.1%; $P < 0.001$) eggs that were heavier (70.6 vs. 68.3 g; $P < 0.001$) than R-fed hens. The BW of LIB-fed hens increased sharply during the first 4 wk of the experiment a period in which these hens gained 14% BW, whereas the R-fed hens gained 3.7% BW (Figure 1). However, for the last 8 wk of the experiment the differences in BW gain between LIB and R hens were quite similar (9.6 vs. 7.9%). The inclusion of cellulose in the diet reduced feed intake (172 vs. 173 and 174 g/d; $P < 0.05$) and BW gain (7.1 vs. 7.8 and 8.6 g/d; $P < 0.01$) and increased the rate of egg production (62.9 vs. 56.9 and 59.8%; $P < 0.05$) compared with the inclusion of inulin or of hens fed the control diet. The effect of fiber inclusion on reducing BW gain was more evident during the last than during the initial part of the experiment (Figure 1). Egg weight, egg mass, and FCR were not affected by the inclusion of fiber in the diet. Increasing the CP content of the diet did not affect any of the performance traits studied except BW gain that was increased (8.3 vs. 7.4 g/d; $P < 0.05$).

Hatchability rates (75.2 vs. 70.9%; $P = 0.07$) and fertility (82.9 vs. 78.6%; $P < 0.05$) decreased, but BW of the newborn chicks increased (46.8 vs. 48.6 g; $P < 0.001$) as the hen aged (Table 3). Hatchability (76.5 vs. 69.6%; $P < 0.01$) and fertility (83.6 vs. 78.0%; $P < 0.05$) rates were higher and the percentage of hatching of fertile eggs tended to be higher (90.7 vs. 87.4%; $P = 0.09$) with R feeding than with LIB feeding. The BW of the newly hatched chicks was higher (46.7 vs. 48.7 g; $P < 0.001$) for R than for LIB-fed hens. The inclusion of inulin or cellulose in the diet had no effect on hatchability or percentage of hatch of fertile eggs but improved fertility (83.4 and 82.9 vs. 75.9%; $P < 0.05$). Neither fiber inclusion nor CP content of the diet affected embryonic mortality rate or BW of the hatched chicks.

### Ovarian Morphology

The number of large yellow follicles (6.1 vs. 5.5; $P < 0.01$) and postovulatory follicles (4.2 vs. 2.6; $P < 0.001$) were lower at 55 than at 45 wk of age but that of small yellow follicles (12.9 vs. 15.7; $P < 0.001$) and white follicles (14.1 vs. 17.7; $P < 0.001$) were higher at 54 wk of age. The diameter of the F1 and F2 follicles

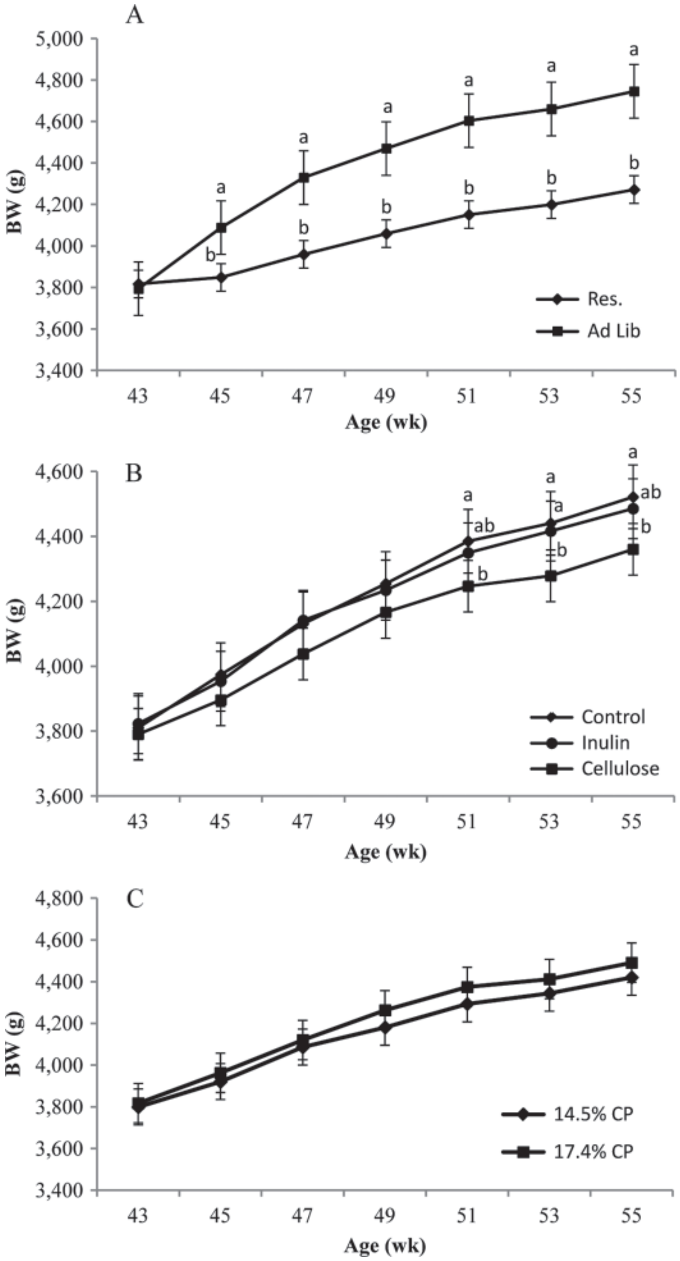


**Figure 1.** Body weight of broiler breeder hens fed A) restricted (Res) or liberally, B) control diet or that diet supplemented with 3% cellulose or 3% inulin, or C) the diet with 14.5 or 17.4% CP. Different superscript letters (a,b) show a significant difference ($P < 0.05$).

increased ($P < 0.001$) with age (Table 4). Hens fed LIB tended ($P = 0.09$) to have more atretic follicles and had larger (28.8 vs. 27.7 mm; $P < 0.05$) F1 follicles than R-fed hens, but no effects were observed for the other ovarian follicle morphology traits. Neither fiber source nor CP content of the diet affected any ovarian morphology traits.

## Egg Quality

Egg shell thickness (29.7 vs. 30.1 mm $\times$ $10^2$; $P <$ 0.001), shell weight (8.4 vs. 8.8% egg weight; $P <$ 0.001), and Haugh units (71.2 vs. 77.9; $P < 0.001$) decreased with age of the hens, whereas yolk weight as percentage of egg weight (32.2 vs. 31.1%; $P < 0.001$) increased (Table 5). Shell breaking strength and shell thickness were not affected by feeding regimen, but the proportion of yolk in the egg was higher (32.1 vs. 31.1%; $P < 0.001$) for LIB than for R-fed hens. Fiber inclusion (either inulin or cellulose) reduced ($P < 0.05$) yolk weight but did not affect any shell or albumen quality trait. The relative weight of the shell increased as the CP content of the diet increased. Yolk color score was not affected by treatment except for hens fed the 17.4% CP diet that had higher pigmentation score than hens fed the 14.5% CP diet ($P < 0.001$).

## Organ Weight

The absolute weight of the liver (91.9 vs. 101.1 g; $P <$ 0.001) and abdominal fat (111.9 vs. 192.0 g; $P < 0.001$) increased with age, whereas the relative weight of the ovary (1.61 vs. 1.45%; $P < 0.05$) and oviduct (1.47 vs. 1.31%; $P < 0.01$) were lower at 45 wk than at 55 wk of age (Table 6). Hens fed LIB had heavier livers (106.8 vs. 86.1 g; $P < 0.001$) and ovaries (70.0 vs. 59.4 g; $P <$ 0.001) and more abdominal fat (178.6 vs. 125.4 g; $P <$ 0.001) than R-fed hens. However, the relative weights of the oviducts were not affected by feeding regimen. Both inulin and cellulose inclusion reduced liver weight (94.8 and 93.8 vs. 100.8 g; $P < 0.05$) and abdominal fat weight (150.8 and 140.4 vs. 164.7 g; $P < 0.05$) but the relative weights of the livers, ovaries, and oviducts were not affected. The weights of livers (92.5 vs. 100.5 g; $P$ $< 0.001$), ovaries (61.2 vs. 68.3 g; $P < 0.05$), and abdominal fat (144.9 vs. 159.1 g; $P < 0.05$) were reduced as the CP content of the diet increased.

# DISCUSSION

## Reproductive Performance and Feeding Regimen

Hens fed LIB ate 20% more feed than R-fed hens which resulted in increased BW gain, excessive fat deposition in the abdominal cavity, and increased lipid content of the liver and ovary (Mohiti-Asli et al., 2012). During the first 2 wk of experiment (43 to 45 wk of age), LIB-fed hens consumed 202 g of feed daily, but feed intake was reduced gradually with age to 185 g/d. This result agrees with data of Chen et al. (2006) who noted a reduction in voluntary feed intake after several days of provision of unlimited amounts of feed. Egg production, fertility rate, and hatching percentage were reduced with LIB feeding, in agreement with data of Chen et al. (2006) who reported that LIB-fed hens had lower egg production and higher incidence of abnormal eggs than R-fed hens.

The BW of the newly hatched chicks were higher with LIB than with R feeding, a finding that was consistent with the heavier eggs of the LIB hens. The number of large yellow follicles was similar for LIB and R-fed hens, but the diameter of F1 follicles was larger

**Table 3.** Effect of feeding regimen and diet on hatchability, fertility, BW of newborn chick, and embryonic mortality

| Item | Hatchability (%) | Hatch of fertile egg (%) | BW of newborn chick (g) | Fertility (%) | Embryonic mortality (%) |
|---|---|---|---|---|---|
| Age (wk) | | | | | |
| 48 | 75.2 | 90.7 | 46.8 | 82.9 | 5.3 |
| 54 | 70.9 | 87.4 | 48.6 | 78.6 | 7.2 |
| SEM[1] | 1.64 | 1.35 | 0.30 | 1.67 | 0.96 |
| Feeding regimen | | | | | |
| Restricted | 76.5 | 90.7 | 46.7 | 83.6 | 5.7 |
| Ad libitum | 69.6 | 87.4 | 48.7 | 78.0 | 5.8 |
| SEM[2] | 1.64 | 1.35 | 0.30 | 1.67 | 0.96 |
| Fiber source | | | | | |
| Control | 70.5 | 90.3 | 47.9 | 75.9[b] | 6.4 |
| Inulin, 3% | 73.2 | 88.8 | 47.5 | 83.4[a] | 5.9 |
| Cellulose, 3% | 75.5 | 88.0 | 47.7 | 82.9[a] | 6.5 |
| SEM[3] | 2.01 | 1.66 | 0.37 | 2.05 | 1.17 |
| CP (%) | | | | | |
| 14.5 | 71.5 | 88.7 | 47.5 | 80.0 | 6.0 |
| 17.4 | 74.6 | 89.3 | 47.9 | 81.6 | 6.5 |
| SEM[4] | 1.64 | 1.35 | 0.30 | 1.67 | 0.96 |
| Effect (*P*-value)[5] | | | | | |
| Age | 0.072 | 0.092 | 0.001 | 0.049 | 0.147 |
| Feeding regimen | 0.004 | 0.089 | 0.001 | 0.020 | 0.448 |
| Fiber source | 0.217 | 0.633 | 0.771 | 0.020 | 0.918 |
| CP | 0.177 | 0.747 | 0.251 | 0.496 | 0.708 |

[a,b]Means with different superscript letter within a column are significantly different ($P < 0.05$).

[1]Standard error of means for age effect (n = 60).

[2]Standard error of means for feeding regimen effect (n = 30).

[3]Standard error of means for fiber source effect (n = 20).

[4]Standard error of means for CP effect (n = 30).

[5]The interactions among main effects were not significant ($P > 0.10$).

**Table 4.** Effects of feeding regimen and type of diet on ovarian follicle morphology

| Item | LYF[1] (>8 mm) | SYF[2] (2 to 8 mm) | White follicle | Atretic follicle | POF[3] | Type 3 follicle[4] | $F_1$[5] (mm) | $F_2$[6] (mm) |
|---|---|---|---|---|---|---|---|---|
| Age (wk) | | | | | | | | |
| 45 | 6.1 | 12.9 | 14.1 | 0.73 | 4.2 | 0.27 | 27.3 | 25.5 |
| 55 | 5.5 | 15.7 | 17.7 | 0.58 | 2.6 | 0.50 | 29.2 | 26.6 |
| SEM[7] | 0.15 | 0.51 | 0.77 | 0.12 | 0.19 | 0.08 | 0.26 | 0.27 |
| Feeding regimen | | | | | | | | |
| Restricted | 5.8 | 14.7 | 16.7 | 0.52 | 3.4 | 0.38 | 27.7 | 25.8 |
| Ad libitum | 5.7 | 13.8 | 15.1 | 0.79 | 3.4 | 0.39 | 28.8 | 26.3 |
| SEM[8] | 0.15 | 0.51 | 0.77 | 0.12 | 0.19 | 0.08 | 0.26 | 0.27 |
| Fiber source | | | | | | | | |
| Control | 5.9 | 13.8 | 15.7 | 0.71 | 3.2 | 0.45 | 28.4 | 26.2 |
| Inulin, 3% | 5.7 | 14.9 | 15.7 | 0.74 | 3.5 | 0.33 | 28.1 | 25.8 |
| Cellulose, 3% | 5.7 | 14.2 | 16.2 | 0.51 | 3.4 | 0.37 | 28.28 | 26.19 |
| SEM[9] | 0.18 | 0.62 | 0.91 | 0.14 | 0.23 | 0.10 | 0.39 | 0.33 |
| CP (%) | | | | | | | | |
| 14.5 | 5.7 | 14.4 | 15.3 | 0.62 | 3.4 | 0.39 | 28.3 | 25.9 |
| 17.4 | 5.8 | 14.1 | 16.4 | 0.69 | 3.3 | 0.38 | 28.2 | 26.2 |
| SEM[10] | 0.15 | 0.51 | 0.77 | 0.12 | 0.19 | 0.08 | 0.26 | 0.27 |
| Effect (*P*-value)[11] | | | | | | | | |
| Age | 0.006 | 0.001 | 0.001 | 0.382 | 0.001 | 0.063 | 0.001 | 0.001 |
| Feeding regimen | 0.655 | 0.212 | 0.133 | 0.092 | 0.976 | 0.986 | 0.005 | 0.146 |
| Fiber source | 0.550 | 0.471 | 0.894 | 0.445 | 0.694 | 0.740 | 0.763 | 0.595 |
| CP | 0.572 | 0.689 | 0.284 | 0.661 | 0.792 | 0.986 | 0.838 | 0.527 |

[1]Number of large yellow follicles (greater than 8 mm in diameter).

[2]Number of small yellow follicles (between 2 and 8 mm in diameter).

[3]Number of postovulatory follicles.

[4]Number of degenerated form of follicle containing nonyolk fluid with low viscosity (over 15 mm in diameter).

[5]Diameter of the first largest ovarian follicle.

[6]Diameter of the second largest ovarian follicle.

[7]Standard error of means for age effect (n = 60).

[8]Standard error of means for feeding regimen effect (n = 30).

[9]Standard error of means for fiber source effect (n = 20).

[10]Standard error of means for CP effect (n = 30).

[11]Remaining interactions were not significant ($P > 0.10$).

**Table 5.** Effects of feeding regimen and type of diet on egg quality

| Item | Shell strength (kg/cm$^2$) | Shell thickness ($10^2$ mm) | Haugh units | Yolk color | Relative weight (% egg weight) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Yolk | Shell | Albumen |
| Age (wk) | | | | | | | |
| 49 | 3.18 | 30.4 | 77.9 | 9.8 | 31.1 | 8.8 | 59.9 |
| 55 | 3.15 | 29.4 | 71.2 | 10.1 | 32.2 | 8.4 | 59.4 |
| SEM[1] | 0.07 | 0.23 | 1.02 | 0.07 | 0.15 | 0.07 | 0.18 |
| Feeding regimen | | | | | | | |
| Restricted | 3.07 | 29.7 | 74.6 | 9.9 | 31.1 | 8.6 | 60.3 |
| Ad libitum | 3.26 | 30.1 | 74.5 | 10.0 | 32.1 | 8.7 | 59.2 |
| SEM[2] | 0.07 | 0.23 | 1.02 | 0.07 | 0.15 | 0.07 | 0.18 |
| Fiber source | | | | | | | |
| Control | 3.08 | 30.0 | 75.4 | 10.1 | 32.0$^{a}$ | 8.6 | 59.4 |
| Inulin, 3% | 3.19 | 29.6 | 74.3 | 9.9 | 31.3$^{b}$ | 8.6 | 60.1 |
| Cellulose, 3% | 3.23 | 30.1 | 74.0 | 9.9 | 31.7$^{ab}$ | 8.7 | 59.6 |
| SEM[3] | 0.09 | 0.28 | 1.24 | 0.09 | 0.18 | 0.09 | 0.23 |
| CP (%) | | | | | | | |
| 14.5 | 3.10 | 29.4 | 75.2 | 9.5 | 31.6 | 8.5 | 59.9 |
| 17.4 | 3.23 | 30.4 | 73.9 | 10.4 | 31.7 | 8.8 | 59.5 |
| SEM[4] | 0.07 | 0.23 | 1.02 | 0.07 | 0.15 | 0.07 | 0.18 |
| Effect (*P*-value)[5] | | | | | | | |
| Age | 0.760 | 0.003 | 0.001 | 0.004 | 0.001 | 0.001 | 0.049 |
| Feeding regimen | 0.057 | 0.247 | 0.953 | 0.526 | 0.001 | 0.451 | 0.001 |
| Fiber source | 0.494 | 0.457 | 0.734 | 0.256 | 0.019 | 0.296 | 0.324 |
| CP | 0.178 | 0.003 | 0.368 | 0.001 | 0.589 | 0.007 | 0.121 |

[a,b]Means with different superscript letter within a column are significantly different ($P < 0.05$).

[1]Standard error of means for age effect (n = 60).

[2]Standard error of means for feeding regimen effect (n = 30).

[3]Standard error of means for fiber source effect (n = 20).

[4]Standard error of means for CP effect (n = 30).

[5]The interactions among main effects were not significant ($P > 0.10$).

**Table 6.** Effects of feeding regimen and type of diet on organ weights

| Item | Hen BW (g) | Organ weight (g) | | | | Relative organ weight (% of BW) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Liver | Ovary | Oviduct | Abdominal fat | Liver | Ovary | Oviduct | Abdominal fat |
| Age (wk) | | | | | | | | | |
| 45 | 3,963 | 91.9 | 63.9 | 58.2 | 111.9 | 2.30 | 1.61 | 1.47 | 2.77 |
| 55 | 4,511 | 101.1 | 65.6 | 58.9 | 192.0 | 2.23 | 1.45 | 1.31 | 4.21 |
| SEM[1] | 32.37 | 1.58 | 2.09 | 1.69 | 4.43 | 0.04 | 0.05 | 0.04 | 0.09 |
| Feeding regimen | | | | | | | | | |
| Restricted | 4,027 | 86.1 | 59.4 | 56.4 | 125.4 | 2.14 | 1.49 | 1.41 | 3.07 |
| Ad libitum | 4,499 | 106.8 | 70.0 | 60.7 | 178.6 | 2.38 | 1.57 | 1.37 | 3.90 |
| SEM[2] | 32.37 | 1.58 | 2.09 | 1.69 | 4.43 | 0.04 | 0.05 | 0.04 | 0.09 |
| Fiber source | | | | | | | | | |
| Control | 4,328 | 100.8$^{a}$ | 63.9 | 59.1 | 164.7$^{a}$ | 2.30 | 1.47 | 1.37 | 3.73$^{a}$ |
| Inulin, 3% | 4,292 | 94.8$^{b}$ | 64.4 | 56.4 | 150.8$^{ab}$ | 2.21 | 1.50 | 1.31 | 3.44$^{ab}$ |
| Cellulose, 3% | 4,091 | 93.8$^{b}$ | 65.9 | 60.1 | 140.4$^{b}$ | 2.28 | 1.62 | 1.48 | 3.30$^{b}$ |
| SEM[3] | 41.29 | 1.98 | 2.56 | 2.13 | 5.55 | 0.05 | 0.07 | 0.06 | 0.11 |
| CP (%) | | | | | | | | | |
| 14.5 | 4,215 | 100.5 | 68.3 | 59.9 | 159.1 | 2.37 | 1.63 | 1.43 | 3.66 |
| 17.4 | 4,259 | 92.5 | 61.2 | 57.1 | 144.9 | 2.16 | 1.44 | 1.35 | 3.32 |
| SEM[4] | 32.37 | 1.58 | 2.09 | 1.69 | 4.43 | 0.04 | 0.05 | 0.04 | 0.09 |
| Effect (*P*-value)[5] | | | | | | | | | |
| Age | 0.001 | 0.001 | 0.562 | 0.760 | 0.001 | 0.212 | 0.036 | 0.009 | 0.001 |
| Feeding regimen | 0.001 | 0.001 | 0.001 | 0.089 | 0.001 | 0.001 | 0.276 | 0.473 | 0.001 |
| Fiber source | 0.001 | 0.035 | 0.849 | 0.466 | 0.013 | 0.378 | 0.246 | 0.126 | 0.034 |
| CP | 0.357 | 0.001 | 0.019 | 0.266 | 0.032 | 0.001 | 0.016 | 0.217 | 0.016 |

[a,b]Means with different superscript letter within a column are significantly different ($P < 0.05$).

[1]Standard error of means for age effect (n = 60).

[2]Standard error of means for feeding regimen effect (n = 30).

[3]Standard error of means for fiber source effect (n = 20).

[4]Standard error of means for CP effect (n = 30).

[5]The interactions among main effects were not significant ($P > 0.10$).

in LIB than in R hens. An enlargement of the diameter of the F1 follicles results in an increase in yolk and egg weight and consequently, in the BW of the newborn chicks. These data are consistent with results of Chen et al. (2006) who reported that enlarged yolk size was an indicator of lipotoxic dysregulation of egg production. They suggested that an increase in yolk weight, coupled with declining egg production, could result from prolonged retention of follicles within the hierarchy of feed-satiated hens. Overfeeding during the phase of reproductive development resulted in an increase in the number of large yellow follicles, which are more likely to be arranged in multiple hierarchies of large follicles (Yu et al., 1992) and result in higher percentage of unsettable eggs. Robinson et al. (1993) reported that the excess of follicular recruitment observed at sexual maturity was reduced at 44 wk of age. Moreover, McGovern et al. (1997) observed a lack of sensitivity of ovarian morphology of 54-wk-old broiler breeders with moderate overfeeding (8 to 16% over that of restricted hens).

Hens fed LIB had lower fertility rate than hens fed R, a finding that is consistent with the higher BW reduced the number of successful matings visually observed in these hens. However, no difference in hatchability of fertile eggs was detected between LIB and R hens. In contrast, Morris et al. (1968) and Enting et al. (2007) reported that hatchability rate was reduced as egg weight increased, and therefore, hatchability should be lower for hens as they aged. These authors suggested that gas exchange rate during the incubation process might be reduced in the heavier eggs, resulting in lower hatchability.

## Inclusion of a Fiber Source

Little information is available regarding the effect of inulin and cellulose inclusion in the diet on reproductive performance of broiler breeder hens. In the current experiment, the inclusion of inulin reduced yolk weight and increased fertility without affecting ovarian morphology. In addition, cellulose reduced BW and feed intake and increased egg production. Studies conducted with rats (Daubioul et al., 2002) and chicks (Akiba and Matsumoto, 1982) demonstrated that the inclusion of inulin or cellulose in the diet reduced feed intake, liver lipids, and BW. Daubioul et al. (2002) and Reimer and Russell (2008) observed that dietary inulin reduced liver lipogenesis in rats, which in turn resulted in a reduction in BW. Daubioul et al. (2000) showed that the inclusion of inulin from chicory root in rat diets for 10 wk decreased BW and reduced the accumulation of TG in the hepatic tissue. These authors reported that inulin effectively lowered plasma TG concentrations in normal rats but obese Zucker rats were resistant to this hypotriglyceridemic effect. The mechanism by which inulin causes a reduction in liver lipogenesis is not known. Kok et al. (1996) and Delzenne (1999) indicated that in the rat, inulin reduced the expression of genes coding for the lipogenic enzymes. Similar mechanism may operate in broilers as Velasco et al. (2010) showed that inulin decreased total hepatic lipid content in rats and broilers. Reimer and Russell (2008) reported a reduction in TG and improved plasma lipid profiles in obese rats when inulin was included in the diet or with the combination of inulin supplementation and higher level of CP. However, in the current trial no significant interaction of the combination of inulin and CP were detected for any of the traits studied.

The inclusion of cellulose in the diet decreased feed intake and BW gain and increased egg production and fertility rate. Egg weight was not affected by cellulose inclusion in diet. The reduction in feed intake with cellulose, observed in the LIB-fed hens, may have been caused by the physical bulking effect of this fiber source.

## CP Content of the Diet

Body weight of the hens was not affected by the level of CP of the diets, consistent with the studies of Keshavarz and Nakajima (1995) and Spratt and Leeson (1987), who indicated that the mature BW of broiler breeder hens was more influenced by energy than by CP intake. In the current trial, birds achieved their mature BW before the start of the experiment, and thus, an excess in CP content of the diet was not expected to affect BW of the hens. These results are in agreement with the data of Joseph et al. (2000) who did not observe any difference in BW of broiler breeder hens when the CP content of the diet was increased from 14 to 18%. These authors also observed an increase in egg weight in hens fed higher protein level, which resulted mostly because of an increase in albumen weight. However, there were no difference in ovary weight, large yellow follicles weight, or in the number of small yellow follicles and large yellow follicles and the weight of the F1 follicle.

## Egg Quality

The LIB-fed hens produced eggs with higher shell strength than the R-fed hens. Walzem et al. (1993) observed higher incidence of egg shell abnormalities in force fed than in control laying hens. However, in this report the hen used were Single Comb White Leghorn and were overfed to 150% of ad libitum consumption, which may be responsible for the shell abnormalities observed. Dietary fiber reduced yolk weight but did not affect egg shell strength or egg shell thickness, in agreement with Shang et al. (2010) who reported no effects of inulin inclusion in egg quality of the laying hen. In contrast, Chen and Chen (2004) observed that inulin improved eggshell quality in laying hens, probably as a result of an increase in calcium absorption. It is suggested that dietary fiber improves the intestinal absorption of minerals in poultry, presumably because of their high binding and sequestering capacities (Roberfroid et al., 2002). In fact, Jiménez-Moreno et al. (2009) reported a significant increase in ash retention in broilers fed 3% oat hulls or 3% sugar beet pulp. An increase in CP content of the diet increased egg yolk pigmentation, possibly because of the higher amount of corn gluten meal used in these diets.

## Organ Weights

The absolute and relative weights of the liver, ovary, and abdominal fat were higher in LIB than in R fed hens, a finding that is consistent with data of Chen et al. (2006) and Renema et al. (1999a,b) in young broiler breeder hens.

Dietary fiber decreased absolute and relative lipid accumulation in the abdominal cavity consistent with data of Yusrizal and Chen (2003) in broilers fed diet supplemented with inulin. Dietary fiber reduced liver weight but did not affect the relative weight of this organ. Daubioul et al. (2002) observed that dietary inulin reduced hepatic TG content and fat deposition in rats. Also, Velasco et al. (2010) reported that dietary inulin decreased total lipid concentration in the liver of broilers. Akiba and Matsumoto (1978) reported that liver weight was increased in force-fed broilers, but the effects were reduced when 4% cellulose was included in the diet.

The absolute and relative weights of the liver, ovary, and abdominal fat were reduced as the CP content of the diet increased. Lilburn and Myers-Miller (1990) reported a decrease in fat pad weight as the CP level of the diet increased from 16 to 23%. In contrast, Joseph et al. (2000) reported that liver and abdominal fat pad weights were not affected by the level of CP of the diet during the prelay and early lay period of broiler breeders. The reduction in liver weight observed with increases in CP content of the diet agrees with data of Rosebrough and Steele (1985) and Rosebrough et al. (2002) who indicated that CP per se is a potent regulator of de novo lipid metabolism in birds.

In conclusion, the increased BW observed with LIB feeding of broiler breeder hens after peak of egg production was associated with excessive liver and abdominal fat deposition which resulted in negative effects on reproductive traits including egg production and fertility. The inclusion of inulin and cellulose in the diet reduced feed intake and BW gain of the hens and improved reproductive performance. An increase in dietary CP reduced hen obesity. The combination of high CP and the inclusion of fiber in the diet did not have any synergistic effect on organ weights or in any of the other traits studied. Inclusion of additional fiber and increases in CP content of the diet are recommended practices to improve reproductive performance of broiler breeder hens.

## REFERENCES


Akiba, Y., and T. Matsumoto. 1977. Effect of dietary fibers on liver lipid accumulation in chicks. Jpn. J. Zootech. Sci. 48:554–562.

Akiba, Y., and T. Matsumoto. 1978. Effects of force-feeding and dietary cellulose on liver lipid accumulation and lipid composition of liver and plasma in growing chicks. J. Nutr. 108:739–748.

Akiba, Y., and T. Matsumoto. 1982. Effects of dietary fibers on lipid metabolism in liver and adipose tissue in chicks. J. Nutr. 112:1577–1585.

AOAC. 2006. Official Methods of Analysis. 18th ed. AOAC Int., Gaithersburg, MD.

Chen, S. E., J. P. McMurtry, and R. L. Walzem. 2006. Overfeeding-induced ovarian dysfunction in broiler breeder hens is associated with lipotoxicity. Poult. Sci. 85:70–81.

Chen, Y. C., and T. C. Chen. 2004. Mineral utilization in layers as influenced by dietary oligofructose and inulin. Int. J. Poult. Sci. 3:442–445.

Daubioul, C., N. Rousseau, R. Demeure, B. Gallez, H. Taper, B. Declerck, and N. Delzenne. 2002. Dietary fructans, but not cellulose, decrease triglyceride accumulation in the liver of obese Zucker fa/fa rats. J. Nutr. 132:967–973.

Daubioul, C. A., H. S. Taper, L. D. De Wispelaere, and N. M. Delzenne. 2000. Dietary oligofructose lessens hepatic steatosis, but does not prevent hypertriglyceridemia in obese Zucker rats. J. Nutr. 130:1314–1319.

Delzenne, N. M. 1999. The hypolipidaemic effect of inulin: When animal studies help to approach the human problem. Br. J. Nutr. 82:3–4.

Enting, H., W. J. Boersma, J. B. Cornelissen, S. C. van Winden, M. W. Verstegen, and P. J. van der Aar. 2007. The effect of low-density broiler breeder diets on performance and immune status of their offspring. Poult. Sci. 86:282–290.

Gilbert, A. B., M. M. Perry, D. Waddington, and M. A. Hardie. 1983. Role of atresia in establishing the follicular hierarchy in the ovary of the domestic hen (*Gallus domesticus*). J. Reprod. Fertil. 69:221–227.

Hocking, P. M. 1993. Effects of body weight at sexual maturity and the degree and age of restriction during rearing on the ovarian follicular hierarchy of broiler breeder females. Br. Poult. Sci. 34:793–801.

Hocking, P. M., M. H. Maxwell, G. W. Robertson, and M. A. Mitchell. 2001. Welfare assessment of modified rearing programmes for broiler breeders. Br. Poult. Sci. 42:424–432.

Jiménez-Moreno, E., J. M. Gonzalez-Alvarado, A. Gonzalez-Serrano, R. Lazaro, and G. G. Mateos. 2009. Effect of dietary fiber and fat on performance and digestive traits of broilers from one to twenty-one days of age. Poult. Sci. 88:2562–2574.

Joseph, N. S., F. E. Robinson, D. R. Korver, and R. A. Renema. 2000. Effect of dietary protein intake during the pullet-to-breeder transition period on early egg weight and production in broiler breeders. Poult. Sci. 79:1790–1796.

Keshavarz, K., and S. Nakajima. 1995. The effect of dietary manipulations of energy, protein, and fat during the growing and laying periods on early egg weight and egg components. Poult. Sci. 74:50–61.

Kok, N., M. Roberfroid, A. Robert, and N. Delzenne. 1996. Involvement of lipogenesis in the lower VLDL secretion induced by oligofructose in rats. Br. J. Nutr. 76:881–890.

Leveille, G. A. 1967. Influence of dietary fat and protein on metabolic and enzymatic activities in adipose tissue of meal-fed rats. J. Nutr. 91:25–34.

Lilburn, M. S., and D. J. Myers-Miller. 1990. Dietary effects on body composition and subsequent production characteristics in broiler breeder hens. Poult. Sci. 69:1126–1132.

Masoro, E. J., I. L. Chaikoff, S. S. Chernick, and J. M. Felts. 1950. Previous nutritional state and glucose conversion to fatty acids in liver slices. J. Biol. Chem. 185:845–856.

McGovern, R. H., R. A. Renema, and F. E. Robinson. 1997. Increased feed allocation does not stimulate increased ovarian development or increased egg output in 54-week-old broiler breeder hens. Can. J. Anim. Sci. 77:177–179.

Mohiti-Asli, M., M. Shivazad, M. Zaghari, S. Aminzadeh, M. Rezaian, and G. G. Mateos. 2012. Dietary fibers and crude protein content alleviate hepatic fat deposition and obesity in broiler breeder hens. Poult. Sci. 91:3107–3114.

Morris, R. H., D. F. Hessels, and R. J. Bishop. 1968. The relationship between hatching egg weight and subsequent performance of broiler chickens. Br. Poult. Sci. 9:305–315.

Pérez-Bonilla, A., M. Frikha, S. Mirzaie, J. García, and G. G. Mateos. 2011. Effects of the main cereal and type of fat of the diet on productive performance and egg quality of brown-egg laying hens from 22 to 54 weeks of age. Poult. Sci. 90:2801–2810.

Reimer, R. A., and J. C. Russell. 2008. Glucose tolerance, lipids, and GLP-1 secretion in JCR:LA-cp rats fed a high protein fiber diet. Obesity (Silver Spring) 16:40–46.

Renema, R. A., F. E. Robinson, M. Newcombe, and R. I. McKay. 1999a. Effects of body weight and feed allocation during sexual maturation in broiler breeder hens. 1. Growth and carcass characteristics. Poult. Sci. 78:619–628.

Renema, R. A., F. E. Robinson, J. A. Proudman, M. Newcombe, and R. I. McKay. 1999b. Effects of body weight and feed allocation during sexual maturation in broiler breeder hens. 2. Ovarian morphology and plasma hormone profiles. Poult. Sci. 78:629–639.

Roberfroid, M. B., J. Cumps, and J. P. Devogelaer. 2002. Dietary chicory inulin increases whole-body bone mineral density in growing male rats. J. Nutr. 132:3599–3602.

Robinson, F. E., J. L. Wilson, M. W. Yu, G. M. Fasenko, and R. T. Hardin. 1993. The relationship between body-weight and reproductive efficiency in meat-type chickens. Poult. Sci. 72:912–922.

Rosebrough, R. W., S. M. Poch, B. A. Russell, and M. P. Richards. 2002. Dietary protein regulates in vitro lipogenesis and lipogenic gene expression in broilers. Comp. Biochem. Physiol. A Mol. Integr. Physiol. 132:423–431.

Rosebrough, R. W., and N. C. Steele. 1985. Energy and protein relationships in the broiler. 1. Effect of protein levels and feeding regimens on growth, body composition, and in vitro lipogenesis of broiler chicks. Poult. Sci. 64:119–126.

Ross Breeder Manual. 2007. Ross 308 Parent Stock Nutrition Specification. Ross Breeders Ltd., Newbridge, Midlothian, UK.

SAS Institute. 2004. SAS User's Guide. Statistics. Version 9.1 ed. SAS Institute Inc., Cary, NC.

Shang, H. M., T. M. Hu, Y. J. Lu, and H. X. Wu. 2010. Effects of inulin on performance, egg quality, gut microflora and serum and yolk cholesterol in laying hens. Br. Poult. Sci. 51:791–796.

Spratt, R. S., and S. Leeson. 1987. Broiler breeder performance in response to diet protein and energy. Poult. Sci. 66:683–693.

Tanaka, K., S. Ohtani, and K. Shigeno. 1983. Effect of increasing dietary energy on hepatic lipogenesis in growing chicks. II. Increasing energy by fat or protein supplementation. Poult. Sci. 62:452–458.

Velasco, S., L. T. Ortiz, C. Alzueta, A. Rebole, J. Trevino, and M. L. Rodriguez. 2010. Effect of inulin supplementation and dietary fat source on performance, blood serum metabolites, liver lipids, abdominal fat deposition, and tissue fatty acid composition in broiler chickens. Poult. Sci. 89:1651–1662.

Walzem, R. L., C. Simon, T. Morishita, L. Lowenstine, and R. J. Hansen. 1993. Fatty liver hemorrhagic syndrome in hens overfed a purified diet. Selected enzyme activities and liver histology in relation to liver hemorrhage and reproductive performance. Poult. Sci. 72:1479–1491.

Yu, M. W., F. E. Robinson, R. G. Charles, and R. Weingardt. 1992. Effect of feed allowance during rearing and breeding on female broiler breeders. 2. Ovarian morphology and production. Poult. Sci. 71:1750–1761.

Yusrizal, and T. C. Chen. 2003. Effect of adding chicory fructans in feed on broiler growth performance, serum cholesterol and intestinal length. Int. J. Poult. Sci. 2:214–219.