Effect of Early Feed Restriction of Varied Severity on Growth Performance, Carcass Composition and Lipid Metabolism in Female Ducks

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Abstract This experiment was carried out using female ducks to determine the effect of feed restriction at early stage of growth of varied severity on subsequent growth performance, carcass composition and lipid metabolism. Seventy-two meat-type female ducks (White Peking) were assigned to four treatments at 7 days of age : *ad libitum* feeding (control) and three treatments, in which daily feed intake were designed to restrict to 80, 60 and 40% of *ad libitum* intake, respectively from 8 to 14 days of age. All the birds were fed *ad libitum* following feed restriction until 47 days of age. A commercial starter diet for broilers (2,900 kcal ME/kg of diet, 23% CP) was supplied to all the birds from 1 to 21 days of age followed by a finisher diet for broilers (3,200 kcal ME/kg of diet, 19% CP) up to 47 days of age. Six ducks from each group were killed at 14 days of age and the remainders were sacrificed at the final day of experiment. The growth rate was significantly lowered by feed restriction but it was completely recovered irrespective of the severity of restriction until the experiment terminated. Weights of muscle and abdominal fat pad were also decreased by the feed restriction at 14 days of age. However, there were no differences between control and feed-restricted groups when the experiment terminated at 47 days of age. Visceral weights and carcass composition were measured only at 47 days of age and no effect of feed-restriction was observed. Lipid metabolism was also significantly affected by the feed restriction at 14 days of age as evidenced by decreases in contents of triglyceride and phospholipid in the liver and serum and activities of liver acetyl-CoA carboxylase and fatty acid synthetase while these effects were not observed in the birds killed at 47 days of age.

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The carcass of ducks is characterized to contain a large amount of fat, which represents over 30% of carcass weight^{2,13,20}. Obesity in ducks is mainly caused by feeding diets with wide energy : protein ratios²⁹, selection for a rapid growth³⁰ and overconsumption²⁷. Like broiler chickens, excessive fat results in not only an undesirable marketing feature but also in production inefficiency. It has been suggested that high fat deposition is one of the major reasons resulting in a poorer feed conversion in ducks,

when compared to broiler chickens¹². Improvement in carcass quality as well as growth performance by decreasing carcass fat deposition has become a hot issue facing the meat-type duck production.

Early feed restriction has been applied to reduce body fat and to improve poor feed efficiency and metabolic diseases in broiler chickens. Plavnik *et al.*²⁵, and Plavnik and Hurwitz²¹⁻²⁴ demonstrated that early feed restriction resulted in an improvement in feed efficiency and a reduction in carcass lipid content

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but not in body weight at a market age in broiler chickens. Many investigators^{9, 10, 14, 28, 34)} confirmed the phenomenon of compensatory growth and reported improvement in feed utilization and/or reduction in body fat deposition in broiler chickens subjected to an early feed restriction. Such phenomenon has been attributed to early feed restriction to alter growth curve²¹⁾, changes in hormonal¹⁶⁾ and lipogenic responses²⁸⁾, and control of hyperplasia and/or hypertrophy of adipocytes^{21, 33, 36)}. Because meat-type ducks contain more carcass fat than broiler chickens at a market age^{2, 20)}, early feed restriction may benefit more duck production than broiler production if fat deposition could be reduced by feed restriction. Unfortunately, the methodology of feed restriction in meat-type ducks has not been adequately explored yet. Furthermore, effect of early feed restriction on lipid metabolism is hardly investigated in ducks. Thus, this study was conducted using ducks to examine the effects of early feed restriction of varying degrees on 1) growth performance and meat-production, 2) abdominal fat pad weights and carcass fat contents, 3) activities of hepatic lipogenic enzymes and 4) lipid contents in the liver and serum.

Materials and Methods

Animals and diets

Seventy-two day-old female meat-type ducks (White Peking) were purchased from a commercial hatchery (Takahashi hatchery, Osaka, Japan). They were reared within a windowless house and an electrically-heated brooder was used to provide a supplemental source of heat until 14 days of age. Temperature in the brooder was maintained at $32 \pm 1^\circ\text{C}$ for 5 days and then gradually reduced in keeping with usual brooding practice where room temperature was maintained at $23 \pm 3^\circ\text{C}$ throughout the experiment. During the pre-experimental period (1 to 7 d), feed was given *ad libitum* to all birds. At 8 days of age, ducks were identified with shank bands and distributed to 4 treatment groups with two replicates of 9 ducks each where the average body weights were similar. The treatments encompassed four levels of feeding regimen, namely an *ad libitum* (control) and 80%, 60% and 40% of *ad libitum* feeding treatments,

respectively. Feed intake in ducks was restricted from 8 to 14 days of age. During this period, daily feed allowance in the restricted ducks was determined by feed intake of the control ducks on the previous day. *Ad libitum* feeding was resumed following feed restriction until the end of the experiment. A commercial starter diet for broilers (2,900 kcal ME/kg of diet, 23% CP) was fed to all birds from 1 to 21 days of age. This was followed by a commercial finisher diet for broilers (3,200 kcal ME/kg of diet, 19% CP) from 22 to 47 days. Body weight was recorded each week individually, whereas feed consumption was determined daily.

General procedure

At 14 and 47 days of age, 6 ducks of each treatment group with similar body weight to the pen average were bled by jugular veins for blood samples (approximately 20 ml per bird) and were killed by decapitation. The sampling and killing of ducks were conducted in rotation. The serum was separated by centrifugation (Model 05P-21, Hitachi koki LTD, Tokyo, Japan) at $650 \times g$ for 10 minutes. The liver and abdominal fat pad were removed immediately and weighed. One part of each liver was put into an ice-cold saline for determination of lipogenic enzyme activities. The remaining liver and serum were stored at -30°C for subsequent analysis of the various lipid fractions. Various lipid fractions were determined using the IATROSCAN (TH-10, Iatron Laboratories Inc. Tokyo, Japan) thin layer chromatography-flame with ionization detector system (TLC-FID) according to Christie and Hunter⁴⁾. At 47 days of age, the remaining 6 ducks of each group were starved overnight to empty the digestive tracts and bled to death through jugular vein. Then, the ducks were blanching at 60°C for about 2 minutes and placed in a rotary drum picker (Tazaki Seisakusho Co. Tokyo, Japan) for 30 seconds to remove feathers. The pinfeather was plucked carefully by hand. In the process of dissection, gastrointestinal tract was cut and opened and washed away its contents. After removing the water with rags, the weights of gizzard and small intestine were determined, then the gastrointestinal tract was returned to the carcass. The carcasses, except for blood, feces and feathers were

frozen at -30°C until further analysis. When mincing, the carcasses from each pen were repeatedly ground four times using a meat grinder (Model WMG-22, Watanabe Seisakusho Co. Japan) with a 5 mm mesh plate. Finally, they were thoroughly ground and mixed by a blender (Model MK-K47-W, National Co. Osaka, Japan) to obtain uniform mixing. Protein, fat and moisture contents of carcasses were determined by the method of AOAC¹⁾. Measurement of the abdominal fat pad, breast (*M. Pectoralis major*) and leg (*M. Femoris* and *M. Cruris*) muscles in this study were based on the procedure of Leeson *et al.*¹³⁾.

Treatment of liver sample

Liver was cut with scissors into small pieces, then homogenized for 30 seconds (Model LK-21, Ultra-disperser, Yamato Co. Japan) in 0.25 M sucrose solution containing 1 mM ethylenediaminetetraacetate-2 Na (EDTA-2 Na) under the ice-bath condition. The homogenates were then centrifuged (Model RS-18, Tomy Seiko, Japan) at $600 \times g$ at 4°C for 10 minutes. The supernatants were recentrifuged (Model 65P, RP 40705 rotor, Hitachi koki LTD, Tokyo, Japan) at $105,000 \times g$ at 4°C for 60 minutes. The supernatants (cytosolic fraction) were used for enzyme activity determinations.

Enzyme assay

Acetyl-CoA carboxylase (EC, 6.2.1.3, ACC) was assayed by H^{14}CO_3 -fixation method²⁶⁾, and fatty acid synthetase (FAS) was assayed by $1\text{-}^{14}\text{C}$ -acetyl-CoA incorporation method⁸⁾. The protein content of solutions used for enzyme assay was determined by the method of Lowry *et al.*¹⁵⁾ using albumin as the standard. Enzyme activities were expressed as nanomole of substrate converted to product per minute per mg protein at 37°C .

Statistical analyses

All data were statistically analyzed using one-way analyses of variance (ANOVA), and significant differences among treatments were determined by Duncan's multiple range test⁵⁾ at the level of $P < 0.05$. Percentages were transformed to arc sine percentages before square root percentages ANOVA was performed.

Results

Effects of early feed restriction on body weight, feed intake and feed conversion ratio of ducks are shown in Table 1. At the end of the 7 days feed restriction, the body weight was smaller for all feed-restricted ducks than for control ducks. At 47 days of age, however, the restricted-refed ducks achieved body weight equal to controls regardless of the severity of feed restriction. The body weight gain from 15 to 47 days of age tended to be higher in previously feed-restricted birds than in control group, so that no significant difference in weight gain was found among the treatment groups throughout the experimental period. Feed intake (15 to 47 days and 7 to 47 days) was significantly lower in restricted-refed ducks than in control ducks and feed conversion ratios (7–47 days) were superior for previously restricted birds.

Effects of early feed restriction on the weights of liver, abdominal fat pad, gizzard, small intestine, breast and leg muscles, and dressed carcass are listed in Table 2. At 14 days of age, the liver and abdominal fat pad weights, expressed as percentage of body weights, linearly decreased with increasing degree of feed restriction, but not different among the treatment groups at 47 days of age. The proportions of breast (*M. Pectoralis major*) and leg (*M. Femoris* and *M. Cruris*) muscles weights to body weights decreased or tended to decrease in feed-restricted ducks at the end of 7 days feed restriction, but did not differ at 47 days of age. The percentage of dressed carcass weight was not affected by early feed restriction, whereas the percentage of gizzard and small intestine tended to increase in previously feed-restricted ducks.

Table 3 shows the effects of early feed restriction on carcass composition in female ducks. Early feed restriction, regardless of severity, did not change the carcass composition of ducks at a market age although ducks fed 40% *ad libitum* tended to reduce carcass fat content.

The effects of early feed restriction on hepatic ACC and FAS activities are presented in Table 4. With increasing degree of feed restriction, hepatic FAS activity decreased at the end of 7 days feed restriction. ACC activity in the liver of feed-restricted ducks

Table 1. Effectes of early feed restriction on body weight, weight gain and feed conversion ratio of female ducks

Variable	<i>Ad libitum</i>	Restricted to		
		80%	60%	40%
Body weight, g/bird ¹⁾				
7 d	170 ± 5	170 ± 4	170 ± 4	170 ± 5
14 d	371 ± 13 ^a	312 ± 8 ^b	272 ± 8 ^c	248 ± 8 ^d
47 d	2,775 ± 60	2,745 ± 60	2,808 ± 48	2,777 ± 62
Weight gain, g/bird ¹⁾				
7-14 d	210 ± 6 ^a	142 ± 1 ^b	102 ± 1 ^c	78 ± 2 ^d
15-47 d	2,404 ± 74	2,433 ± 23	2,536 ± 23	2,529 ± 73
7-47 d	2,605 ± 68	2,575 ± 24	2,638 ± 22	2,607 ± 73
Feed intake, g/bird ²⁾				
7-14 d	507 ± 2	365 ± 7	276 ± 5	183 ± 12
15-47 d	6,898 ± 67 ^a	6,320 ± 55 ^b	6,816 ± 25 ^a	6,243 ± 98 ^b
7-47 d	7,405 ± 65 ^a	6,685 ± 48 ^b	7,092 ± 20 ^a	6,426 ± 102 ^b
Feed conversion ratio, g/g ²⁾				
7-47 d	2.84 ± 0.05 ^a	2.60 ± 0.05 ^{bc}	2.69 ± 0.03 ^b	2.47 ± 0.03 ^c

¹⁾ Average and SE for 18 ducks (7-14 d) and for 12 ducks (15-47 d) each treatment.

²⁾ Data are presented as the means and SE for two replicates. Different superscripts within the same row indicate significant difference ($P < 0.05$).

tended to decrease but not significantly. At 47 days of age, however, previously feed-restricted ducks had similar values in the activities of ACC and FAS in comparison with control ducks.

The effects of early feed restriction on the contents of various lipid fractions in the liver and serum of female ducks are shown in Tables 5 and 6. At 14 days of age, the hepatic triglyceride content, as well as the serum triglyceride and phospholipid concentrations, significantly decreased in the feed-restricted ducks. At 47 days of age, however, lipid fractions in the liver and serum of restricted-refed ducks were not different from those of control ducks. During the period of feed restriction and refeeding, neither cholesterol ester nor free cholesterol levels in the liver and serum were affected by feed restriction.

Discussion

Plavnik and Hurwitz²⁴⁾ showed a complete growth compensation at 56 days of age when fed restrictively at an early age in broiler chickens. In this study, we subjected ducks to an early feed restriction similar to

that used by Plavnik and Hurwitz²⁴⁾, and showed that restricted-refed ducks achieved body weight equal to those of controls at 47 days of age, irrespective of the severity. This observation indicated that ducks are more tolerant to severe feed restriction at early stage of growth than broiler chickens. It has been reported that hyperphagia and morphological adaptations of digestive tract (e.g. increase in weight) in restricted-refed broilers were the major contributing factors to compensatory growth and improved feed efficiency³⁵⁾. The present study clearly showed that feed restriction induces a typical concave growth in female duck. During recovery, the restricted-refed ducks gained more weight while consumed less feed than control ducks. But the difference was not statistically significant due to the number of observation. Weights of gizzard and small intestine did not increase by refeeding (Table 2). Obviously, compensatory growth associated with improved feed efficiency in those ducks could not be interpreted by hyperphagia or adaptive changes of digestive tracts. In rat, Kershaw *et al.*¹¹⁾ and Windmarsh *et al.*³²⁾ demonstrated that

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Table 2. Effectes of early feed restriction on weight on liver, abdominal fat pad, gizzard, small intestine, breast and leg muscles, and dressed carcass in female ducks

Variable	<i>Ad libitum</i>	Restricted to		
		80%	60%	40%
----- (% of body weight) -----				
Liver				
14 d	3.28±0.25 ^{al)}	2.84±0.11 ^{ab}	2.78±0.11 ^b	2.57±0.12 ^b
47 d	1.84±0.08	1.88±0.07	1.75±0.08	1.82±0.05
Abdominal fat pad				
14 d	0.33±0.03 ^a	0.21±0.05 ^{ab}	0.16±0.05 ^{bc}	0.12±0.05 ^c
47 d	1.88±0.13	1.99±0.13	2.11±0.08	2.00±0.11
Right breast muscle				
14 d	0.56±0.03 ^a	0.51±0.02 ^a	0.47±0.01 ^b	0.45±0.02 ^b
47 d	3.71±0.11	3.69±0.20	3.72±0.13	3.67±0.11
Right leg muscle				
14 d	5.83±0.19 ^a	5.50±0.33 ^{ab}	5.27±0.16 ^{ab}	4.83±0.47 ^b
47 d	4.22±0.12	4.50±0.28	4.02±0.13	4.28±0.17
Gizzard				
47 d	2.96±0.16	3.03±0.08	3.06±0.18	3.07±0.25
Small intestine				
47 d	2.08±0.20	2.02±0.20	2.19±0.35	2.29±0.41
Dressed carcass ²⁾				
47 d	85.5±0.65	85.0±0.54	86.9±1.86	86.2±0.76

¹⁾ Average and SE for 6 ducks (14 d) and for 12 ducks (47 d) each treatment.

²⁾ Dressed carcass percentage=carcass weight/body wight×100%. Different superscripts within the same row indicate significant difference (P<0.05).

Table 3. Effectes of early feed restriction on carcass composition of female ducks at 47 days of age

Variable	<i>Ad libitum</i>	Restricted to		
		80%	60%	40%
		----- (%) -----		
Protein	14.1±0.23 ¹⁾	14.1±0.12	14.0±0.10	14.3±0.35
Fat	28.1±0.98	28.1±0.49	28.5±1.13	27.6±1.54
Moisture	55.3±0.77	55.4±0.44	54.7±1.45	55.5±1.23

¹⁾ Data are presented as means and SE for 6 ducks per treatment. Different superscripts within the same row indicate significant difference (P<0.05).

dietary restriction increased the absorption rate of amino acids in the intestine. Nitsan *et al.*¹⁸⁾ also reported that digestibility and activities of digestive

enzymes increased in feed-restricted chicks. It seems likely that metabolic shift in enhanced digestion and absorption of nutrients occurred in restricted-refed

Table 4. Effectes of early feed restriction on activities of acetly-CoA carboxylase (ACC) and fatty acid synthetase (FAS) in the liver of female ducks

Enzymes	<i>Ad libitum</i>	Restricted to		
		80%	60%	40%
----- (nmole/min/mg protein) -----				
Acetly-CoA carboxylase				
14 d	2. 91±0. 21 ¹⁾	2. 90±0. 22	2. 60±0. 36	2. 55±0. 69
47 d	4. 14±1. 05	4. 12±0. 87	4. 40±1. 09	4. 63±0. 89
Fatty acid synthetase				
14 d	3. 48±0. 37 ^a	2. 51±0. 45 ^{ab}	2. 03±0. 35 ^b	2. 08±0. 19 ^b
47 d	1. 32±0. 50	0. 99±0. 37	1. 00±0. 33	1. 16±0. 43

¹⁾ Values represent means±SE for 6 ducks per treatment. Different superscripts within the same row indicate significant difference (P<0.05).

Table 5. Effectes of early feed restriction on lipids contents in the liver of female ducks

Variable	<i>Ad libitum</i>	Restricted to		
		80%	60%	40%
		----- (mg/g liver) -----		
14 d				
Triglyceride	16.96±4.47 ^{a1)}	5.50±0.82 ^b	5.38±1.62 ^b	5.65±0.95 ^b
Feel cholesterol	3.06±0.19	3.36±0.09	3.15±0.06	3.07±0.10
Phospholipid	21.55±2.29	21.15±2.29	20.42±1.63	21.16±1.20
47 d				
Triglyceride	7.51±2.38	11.06±4.08	6.82±3.30	4.84±0.90
Feel cholesterol	3.12±0.27	2.93±0.15	3.27±0.07	3.17±0.22
Phospholipid	23.59±2.67	21.96±2.39	17.92±1.38	17.78±1.82

¹⁾ Values represent means±SE for 6 ducks per treatment. Different superscripts within the same row indicate significant difference (P<0.05).

ducks, which results in compensatory growth and improved feed efficiency. Detailed studies on nutrient metabolism in restricted-refed ducks are needed to elucidate the mechanism involved in improvement of feed efficiency.

Newcombe *et al.*¹⁷⁾ observed a reduction in breast meat yield for broilers at market age due to early feed restriction. The present study showed that reduced weights of breast and leg muscles in feed-restricted ducks occurred at the end of the 7 days feed restriction, but not at a market age (Table 2). Pinchasov *et al.*¹⁹⁾ reported that feed deprivation caused a decrease

in the breast muscle weight and refeeding resulted in an increase in growth rate of breast muscles. Hayashi *et al.*⁷⁾ showed that fasting-refeeding broiler chickens exhibited an increased rate of muscle protein turnover during the refeeding period. Knizetova *et al.*¹²⁾ pointed out that the intensive growth of breast muscles in ducks occurred between 6–8 weeks of age. In the present study, we also demonstrated that early feed restriction did not affect the dressed carcass percentage of ducks at market age, suggesting that meat yield of ducks was unchanged when feed restriction was imposed at an early age.

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Table 6. Effectes of early feed restriction on lipids contents in the serum of female ducks

Variable	<i>Ad libitum</i>	Restricted to		
		80%	60%	40%
----- (mg/100 ml serum) -----				
14 d				
Cholesterol ester	214. 40 ±10. 71 ¹⁾	189. 43 ± 7. 22	186. 34 ± 8. 82	207. 26 ± 9. 85
Triglyceride	47. 61 ± 3. 92 ^a	20. 44 ± 2. 39 ^b	22. 25 ± 2. 69 ^b	24. 95 ± 4. 66 ^b
Free cholesterol	65. 43 ± 3. 46	63. 47 ± 4. 27	61. 99 ± 5. 51	66. 66 ± 3. 45
Phospholipid	255. 11 ±26. 51 ^a	188. 50 ±21. 82 ^b	170. 86 ±10. 13 ^b	162. 62 ± 9. 37 ^b
47 d				
Cholesterol ester	176. 64 ±16. 05	188. 86 ± 8. 97	163. 48 ±10. 93	168. 65 ± 3. 68
Triglyceride	32. 47 ± 5. 61	39. 57 ± 2. 65	31. 51 ± 2. 61	34. 52 ± 5. 79
Free cholesterol	52. 71 ± 3. 21	50. 48 ± 2. 03	47. 40 ± 1. 97	45. 92 ± 2. 15
Phospholipid	205. 35 ±22. 59	237. 86 ±31. 83	214. 99 ±22. 44	229. 45 ±28. 50

¹⁾ Values represent means ± SE for 6 ducks per treatment. Different superscripts within the same row indicate significant difference ($P < 0.05$).

Rosebrough *et al.*²⁸⁾ showed that early feed restriction in broiler chickens resulted in a decrease in body fat content without reducing the general performance at a market age. They demonstrated that reduced body fat deposition was due to suppression of the activities of lipogenic-related enzymes. In this study, we observed that activities of fatty acid synthetase (FAS) in feed-restricted ducks were depressed at the end of feed restriction at 14 days of age (Table 4). The carcass fat content at a market age was not different among the treatment groups in the present experiment although it has been reported that carcass fat content of ducks was sensitive to change in amount of feed intake at a later stage of growth³⁾. It is likely that resumption of *ad libitum* feeding allow feed-restricted ducks to exhibit compensatory growth not only in muscle tissues but also in adipose tissues. This hypothesis could be partly proven by carcass fat contents, lipogenic enzyme activities and lipid contents in the restricted-refed ducks (Tables 3, 4, 5 and 6). Many factors may influence the effect of early feed restriction on reducing the body fat content. Summers *et al.*³¹⁾ reported that female broilers were less responsive than male broilers in reducing abdominal fat weight due to early feed restriction. Campbell *et al.*³⁾ stated that female ducks ac-

cumulated energy more as fat and less as protein than males. On the other hand, Evans⁶⁾ showed that fat depots in the domestic duck occur first in inguinal region at early stage of growth, following in subcutaneous tissue at younger age, and finally in abdominal adipose tissue at a later stage of growth. These observations suggest that the sex and timing of feed restriction may be the important factors affecting success in reducing carcass fat content of ducks.

In conclusion, ducks subjected to early feed restriction from 8 to 14 days of age fully recovered body weight and meat yield and improved feed efficiency at a market age. Success in reducing carcass fat deposition by early feed restriction in meat-type ducks will contribute to selecting a suitable method.

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