

Effects of early feed restriction programs on production performance and hormone level in plasma of broiler chickens

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Abstract Age, duration and intensity of feed restriction of broiler chickens were studied by $L_9(3^4)$ orthogonal experiment. Broiler production performance and meat color were measured to evaluate the effects of feed restriction and explore the superior FR program. A total of 250 1-day-old Ross 308 chicks were selected and randomly allocated to ten groups, including one feed ad libitum (AL) group and nine feed restriction (FR) groups; each group had 5 pens with 5 chickens each. Broilers ($T_5D_7I_{90}$), feed-restricted to 90% from day 5 to day 11, had the highest body weight (BW), carcass weight, eviscerated weight, leg muscle weight and breast muscle weight, as well as muscle ratio. While broilers ($T_5D_{14}I_{70}$), feed-restricted to 70% from day 5 to day 18, had the lowest. Triiodothyronine (T_3) and growth hormone (GH) decreased while thyroxine (T_4) and the ratio of T_4/T_3 increased in FR broilers. Feed conversion ratio, abdominal fat ratio, whole eviscerated weight ratio and lightness (L^*) and yellow/blue (b^*) value of leg muscle color increased in FR broilers ($P > 0.05$). $T_5D_{14}I_{70}$ had the lowest red/green (a^*) color value of leg muscle and the highest L^* and b^* color values of breast muscle ($P > 0.05$). FR groups except $T_{10}D_{14}I_{90}$ had lower a^* color value of breast muscle than AL. FR program of $T_5D_7I_{90}$ resulted in superior production performance and higher capability of meat production. Broilers feed-restricted $T_5D_{14}I_{70}$ were stunted with the lowest muscle growth capability and deteriorated in the breast muscle color. FR improved leg muscle color and increased broiler byproduct production. Lower T_3 and GH concentration and higher T_4/T_3 ratio in plasma were related with the increased feed conversion rate and fat deposition in FR broilers; however, they had no relation with meat production and growth rate.

Keywords feed restriction, broiler, production performance, meat color, hormone level

Introduction

Broiler breeds are intensively selected for higher growth rate, which results in higher body mass, excessive fat deposition, lameness, and higher mortality rate (Buyse et al., 1987; Govaerts et al., 2000; Baghbanzadeh and Decuyper, 2008). Feed restriction (FR) in the early stage was beneficial for improving feed efficiency and decreasing feeding cost (Lippens et al., 2000; Mahmood et al., 2007). Animals can adjust physiological metabolism and acclimatize themselves to the deleterious stimulus, and therefore, the early adjustment would keep until the late stage of life. Metabolic

programming is defined as a physiological process whereby the early adaptation to a nutritional stress, which permanently changes in physiology and the metabolism of organism, continues to be expressed even in the absence of the stress (Zhan et al., 2007). Although early FR reduces growth performance, the compensatory growth in the refeeding period will be attained to accelerate organism growth to reach the weight of animals (Tůmová et al., 2002; Marek et al., 2006).

Growth of both birds and mammals depends on direct effects of T_4 and its active form T_3 and also on the interactions between thyroid hormones and GH-IGF-I-growth axis (Scanes, 2009). Plasma T_3 is associated with protein synthesis and energy production and can increase the metabolism rate and the need of oxygen and heat production of broilers. Thyroid hormones play a crucial role in thermoregulation in avian species, and plasma T_3 levels are positively correlated

Received March 25, 2010; accepted April 14, 2010

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with heat production. Previous research in poultry showed that FR may modify the plasma levels of T₃, T₄ and GH to modulate the energy metabolism and growth (McMurtry et al., 1998; Zhan et al., 2007).

Early-age feed or nutrient restriction (qualitative or quantitative) or light restriction to slow down the growth rate seems practically a viable method (Baghbanzadeh and Decuypere, 2008). Diversification in response to FR is dependent on duration, intensity and timing of nutrient reduction (Yu and Robinson, 1992; Yang et al., 2009). In general, prolonged severe nutritional deficit at an early age results in permanent stunting of animals. With an increase in duration of undernutrition, chronic malnutrition represents a permanent stress for organs, and complete growth correction becomes more unlikely. The differences between restricted and AL feed chickens have been well documented; however, more effective FR programs have not been studied. We took orthogonal experiment to study the effects of FR programs on production performance, feed conversion ratio and meat quality to find the superior FR program for broiler chickens, to measure hormone levels and explore the FR mechanism of growth and metabolism of birds.

Materials and methods

Experimental animals and experiment design

The feeding experiment was taken at the Specimen Garden in Agricultural University of Hebei, China, from May 24th to July 5th, 2009. A total of 250 1-day-old Ross chicks, equally divided between males and females, were obtained from a local commercial hatchery and randomly assigned to 50 floorless portable metal pens. The 50 experiment units were divided into one feed ad libitum (AL) group and nine feed restriction (FR) experimental groups with 5 pens each group and 5 chickens in each pen. The body weight (BW) differences of chickens between groups had no statistical significance. Our experiment referred to three factors with three levels each, including age (5-, 7- and 10-day-old chickens), duration (for 7, 10 and 14 days) and intensity (70%, 80%, and 90%) (Table 1). The nine FR experimental groups were designed as L₉(3⁴) orthogonal experiment. The intensity of FR was the ratio of daily ration to the intake of the AL group chickens the day before. For example, 5-day-old T₅D₇I₉₀ took 90 percent of the feed intake of AL at age of 4 days. Commercial Broiler Production Technology Regulation (GB/T 19664–2005) was used as a reference for all management conditions. Birds were fed with a corn-soybean meal basal diet formulated containing 22% crude protein, 13.4 MJ·kg⁻¹ energy metabolism and all recommended vitamins and minerals. Feed was available freely for the AL broilers while FR broilers fed ad libitum merely before and after the feed restriction. Water was available freely for all the birds during the whole feeding

Table 1 L₉(3⁴) orthogonal experiment design of feed restriction

group		age/d	duration/d	intensity/%
FR	T ₅ D ₇ I ₉₀	5	7	90
	T ₅ D ₁₀ I ₈₀	5	10	80
	T ₅ D ₁₄ I ₇₀	5	14	70
	T ₇ D ₇ I ₇₀	7	7	70
	T ₇ D ₁₀ I ₉₀	7	10	90
	T ₇ D ₁₄ I ₈₀	7	14	80
	T ₁₀ D ₇ I ₈₀	10	7	80
	T ₁₀ D ₁₀ I ₇₀	10	10	70
	T ₁₀ D ₁₄ I ₉₀	10	14	90
AL		0	0	100

period. After FR, all the birds were fed ad libitum up to 42 days old.

Measurements

Feed intake of all FR was recorded before FR, and that of AL was recorded daily from the age of 4 days to 22 days as a daily-ration criterion for the FR broilers. After feed restriction, feed intake of every group was recorded weekly. BW of broilers in each replicate was measured at the age of 24, 36 and 42 days. One 24-day-old and one 42-day-old broiler in each replicate were slaughtered by cutting the jugular veins and carotid arteries, while carcass weight and whole eviscerated weight were measured. Abdominal fat, leg muscle and breast muscle were excised and weighted, respectively. Blood samples were taken. T₃, T₄ and GH concentrations in plasma of group of T₅D₇I₉₀, T₅D₁₄I₇₀ and AL were measured with radioimmunoassay by Beijing North Institute of Biological Technology. The color of leg and breast muscle was measured within 24 h after slaughter with WSC-s colorimeter (Shanghai Precision & Scientific Instrument Co., LTD).

Carcass weight was the mass of a carcass without blood, feather, head and neck, and feet and paw. Whole eviscerated weight was the mass of a carcass excluding viscera (except kidney and lung) and gland (including thymus and bursa of Fabricius). RA, RL, RB and RM represent the ratio of weight of abdominal fat, leg muscle, breast muscle, and leg and breast muscle together to whole eviscerated weight, respectively. RC and RW represent the ratio of carcass weight and whole eviscerated weight to BW, respectively.

Statistical analysis

One-way ANOVA was carried out by SPSS 16.0 to analyze the effects of FR on production performance of broilers. Difference between groups was analyzed by least significant difference (LSD). Data was presented as mean±SE.

All statements of significance were based on testing at $P < 0.05$.

Results

Production performance

BW, carcass weight and whole eviscerated weight are shown in Table 2. The results revealed that BW, carcass weight and whole eviscerated weight of T₅D₇I₉₀ were all significantly the highest on day 24 and day 42, followed by those of AL, T₁₀D₇I₈₀ and T₇D₁₀I₉₀, while those of T₅D₁₄I₇₀ were significantly the lowest. However, at the day of 36, BW of AL was the highest with that of T₅D₇I₉₀ significantly higher

than that of T₅D₁₄I₇₀ (the lowest) and T₇D₁₄I₈₀. Moreover, the whole eviscerated weight of T₅D₇I₉₀ was significantly higher than that of T₅D₁₄I₇₀, T₇D₇I₇₀, T₇D₁₄I₈₀, T₁₀D₇I₈₀ and T₁₀D₁₀I₇₀, while T₅D₁₄I₇₀ had significantly lower whole eviscerated weight than that of any other group at the day of 24 (Table 2).

Table 3 shows the ratio of carcass and whole eviscerated. AL broilers had a higher ratio of carcass weight to body weight (RC) compared with FR broilers except T₁₀D₇I₈₀ (the highest at 24th day) and T₁₀D₁₀I₇₀ (the highest at 42nd day), and T₅D₁₄I₇₀ and T₇D₇I₇₀ were almost the lowest all along. RW of T₅D₁₄I₇₀ was the lowest at the 24th and 42nd days. RW increased with days, while RC changed insignificantly from 24 day-old to 42 day-old, which showed that broilers presented their capability of meat production at age of later

Table 2 Body weight, carcass weight and whole eviscerated weight of every group ($\bar{X} \pm SE(g)$)

group		body weight			carcass weight		whole eviscerated weight	
		24th day	36th day	42nd day	24th day	42nd day	24th day	42nd day
FR	T ₅ D ₇ I ₉₀	744.0±12.0^e	1445.8±19.6 ^{cd}	1865.3±67.8^c	683.3±15.7^g	1694.3±59.4^d	460.5±6.76^g	1250.5±45.4^c
	T ₅ D ₁₀ I ₈₀	689.4±20.0 ^{cd}	1413.5±33.8 ^{bcd}	1633.5±35.2 ^b	633.8±32.1 ^{def}	1488.8±34.2 ^{bc}	431.0±33.2 ^{efg}	1093.8±28.5 ^b
	T ₅ D ₁₄ I ₇₀	<u>606.6±16.1^a</u>	<u>1225.6±75.3^a</u>	<u>1421.0±52.3^a</u>	<u>529.0±19.6^a</u>	<u>1250.3±27.4^a</u>	<u>334.0±24.5^a</u>	<u>941.6±42.2^a</u>
	T ₇ D ₇ I ₇₀	672.0±27.5 ^{bc}	1384.8±36.1 ^{bcd}	1635.8±51.0 ^b	558.0±66.8 ^{ab}	1481.0±31.3 ^{bc}	381.3±23.1 ^{bc}	1081.3±28.4 ^b
	T ₇ D ₁₀ I ₉₀	723.0±11.8 ^{de}	1397.5±37.1 ^{bcd}	1678.5±33.6 ^b	647.6±26.4 ^{efg}	1510.5±30.2 ^{bc}	433.6±23.2 ^{efg}	1092.4±20.7 ^b
	T ₇ D ₁₄ I ₈₀	635.4±16.2 ^{ab}	1324.4±7.5 ^{ab}	1634.0±61.9 ^b	575.8±32.9 ^{bc}	1476.8±66.3 ^{bc}	378.6±22.9 ^b	1029.0±44.6 ^{ab}
	T ₁₀ D ₇ I ₈₀	728.2±14.0 ^{de}	1397.8±37.1 ^{bcd}	1676.5±63.1 ^b	669.2±13.7 ^{fg}	1466.5±41.2 ^{bc}	441.6±33.5 ^{fg}	1111.0±38.8 ^b
	T ₁₀ D ₁₀ I ₇₀	657.6±11.6 ^{bc}	1403.5±38.9 ^{bcd}	1662.3±58.6 ^b	600.8±24.0 ^{cd}	1450.8±44.5 ^{bc}	398.8±17.6 ^{bcd}	1098.6±47.4 ^b
	T ₁₀ D ₁₄ I ₉₀	685.2±17.7 ^{bcd}	1349.2±29.0 ^{bc}	1648.5±76.8 ^b	620.2±27.4 ^{de}	1402.0±52.5 ^b	415.8±25.0 ^{cde}	1065.2±44.7 ^b
AL		730.8±22.0 ^{de}	1457.5±25.4^d	1724.0±30.1 ^{bc}	651.5±12.5 ^{efg}	1565.0±28.1 ^c	447.8±19.9 ^{fg}	1131.4±33.6 ^b

Note: The same column data marked without the same superscripts differ significantly ($P < 0.05$). The maximum values in each column are in bold. The minimum values in each column are underlined. The same as below tables.

Table 3 Production performance of every group ($\bar{X} \pm SE(\%)$)

group		RC		RW		RB		RL		RA		RM	
		24th day	42nd day	24th day	42nd day	24th day	42nd day	24th day	42nd day	24th day	42nd day	24th day	42nd day
FR	T ₅ D ₇ I ₉₀	91.1±1.2	90.4±0.9	61.7±0.8	67.1±0.7	25.4±0.4	26.2±1.8	19.8±0.6	23.9±1.1	1.6±0.3	2.4±0.3	45.2±1.2	50.2±1.5
	T ₅ D ₁₀ I ₈₀	89.9±0.9	90.5±1.4	61.1±0.6	66.2±0.6	23.7±0.9	25.6±1.3	20.9±0.4	21.4±1.4	1.7±0.2	2.4±0.3	44.6±1.3	47.0±1.4
	T ₅ D ₁₄ I ₇₀	<u>89.9±1.1</u>	<u>88.7±1.9</u>	<u>56.8±1.8</u>	<u>63.8±0.9</u>	24.1±0.8	<u>23.9±1.4</u>	20.0±0.8	22.9±1.3	1.2±0.4	2.4±0.4	44.0±1.4	<u>46.8±1.2</u>
	T ₇ D ₇ I ₇₀	<u>86.3±3.4</u>	<u>88.5±2.3</u>	59.2±1.3	64.2±0.7	23.5±0.3	25.4±0.9	20.5±0.7	22.4±1.2	1.1±0.2	1.9±0.2	43.9±1.1	47.8±1.5
	T ₇ D ₁₀ I ₉₀	89.6±1.5	90.3±0.3	60.0±1.1	66.5±0.5	24.7±0.7	<u>23.7±0.7</u>	20.8±1.1	23.1±3.5	1.3±0.3	1.9±0.3	45.5±1.4	46.8±1.0
	T ₇ D ₁₄ I ₈₀	90.6±0.7	89.6±0.7	59.6±1.2	64.8±0.7	22.6±0.6	24.4±0.6	<u>19.6±0.5</u>	22.7±1.2	1.3±0.4	1.9±0.3	42.1±1.2	47.1±0.9
	T ₁₀ D ₇ I ₈₀	92.0±0.9	91.6±1.1	60.6±1.4	67.6±0.6	24.7±0.7	26.8±1.2	20.9±0.8	<u>21.1±1.8</u>	1.6±0.1	2.2±0.4	45.6±1.4	48.2±1.7
	T ₁₀ D ₁₀ I ₇₀	91.4±0.4	91.8±1.2	60.6±0.5	67.5±0.9	23.3±0.5	25.3±1.3	20.0±0.8	24.6±1.2	<u>1.0±0.4</u>	2.3±0.2	43.3±1.7	49.8±1.4
	T ₁₀ D ₁₄ I ₉₀	90.6±1.3	90.3±0.6	60.7±0.9	66.5±0.8	25.7±0.9	25.5±2.0	21.0±0.7	23.6±0.8	1.3±0.2	2.3±0.2	46.7±1.8	49.3±1.0
AL		91.1±0.8	91.3±1.2	61.4±0.7	67.7±0.5	25.1±0.6	26.0±1.1	20.9±0.6	22.5±0.9	1.3±0.4	<u>1.7±0.4</u>	46.0±1.2	48.4±1.1

Note: RC and RW represent the ratio of carcass weight and whole eviscerated weight to body weight respectively. RB, RL, RA and RM were the ratio of weight of breast muscle, leg muscle, abdominal fat, and muscle of leg and breast to whole eviscerated weight, respectively. The maximum value in each column is in bold. The minimum value and the second minimum in each column are underlined.

days. The whole eviscerated was the carcass excluding viscera (except kidney and lung) and gland including thymus and bursa of Fabricius. AL broilers had higher RW than all the FR broilers at the market age, which indicated that FR increased in the byproduct production of broilers. All the differences were not significant statistically.

RB, RL, RA and RM are shown in Table 3. RB of FR except T₅D₇I₉₀ and T₁₀D₁₄I₉₀ at the 24th day was all lower than that of AL, and at the 42nd day, except T₅D₇I₉₀ and T₁₀D₇I₈₀, the FR still had lower RB than AL, but it did not reach the significant level. There was an increasing trend of RB with an increase in age except T₅D₁₄I₇₀ and T₇D₁₀I₉₀. RL of FR at the 42nd day except T₅D₁₀I₈₀ and T₁₀D₇I₈₀ was all higher than that of AL but without significant lowerness. RB and RL increased with age, which indicates that broilers present meat production at the age of later days. T₅D₇I₉₀ had the highest RM, while T₅D₁₄I₇₀ had the lowest. RA of all FR was higher than that of AL at the 42nd day. In general, RA, RL, RB and RM among groups were significantly different statistically.

Meat production and meat color

The weights of leg muscle, breast muscle and abdominal fat are shown in Table 4. The leg muscle and breast muscle of T₅D₇I₉₀ were the highest except the leg muscle at the 24th day, with little significant difference from that of AL broilers except leg muscle at the 42nd day. The weights of leg and breast muscle of T₅D₁₄I₇₀ were the lowest and were significantly lower than that of AL at the 24th and 42nd days. The weight of abdominal fat of T₅D₁₄I₇₀ was lower at the 24th day but higher at the 42nd day, and that of T₅D₇I₉₀ was higher at the 24th and 42nd days than that of AL, without significant differences between groups.

Color values of leg muscle and breast muscle at the 42nd day are shown in Table 5. The leg muscle color of T₁₀D₁₀I₇₀ was missed, while the other groups were all measured carefully. Muscle color had no significant difference between groups. *L** and *b** of leg muscle in FR were all lower than those of AL. T₅D₁₄I₇₀ had the lowest *a** value of leg muscle

Table 4 Weight of leg muscle, breast muscle and abdominal fat ($\bar{X} \pm SE(g)$)

group		leg muscle		breast muscle		abdominal fat	
		day 24	day 42	day 24	day 42	day 24	day 42
FR	T ₅ D ₇ I ₉₀	90.8±3.2 ^{bc}	299.6±20.2^d	116.4±1.3^f	328.4±29.4^c	7.37±0.90	30.42±3.78
	T ₅ D ₁₀ I ₈₀	90.6±4.0 ^{bc}	239.0±12.3 ^{abc}	100.5±5.4 ^{cd}	267.2±16.1 ^{ab}	7.17±0.88	25.55±3.87
	T ₅ D ₁₄ I ₇₀	<u>68.8±4.2^a</u>	<u>216.4±16.2^a</u>	<u>82.8±4.3^a</u>	<u>225.6±15.8^a</u>	4.34±0.70	21.92±3.15
	T ₇ D ₇ I ₇₀	75.2±7.6 ^a	236.0±4.1 ^{abc}	89.6±4.0 ^{ab}	269.2±14.8 ^{ab}	4.50±0.65	20.31±2.49
	T ₇ D ₁₀ I ₉₀	90.8±6.8 ^{bc}	252.8±5.9 ^{bc}	106.8±3.3 ^{de}	258.4±10.1 ^{ab}	5.70±0.73	20.97±3.77
	T ₇ D ₁₄ I ₈₀	74.1±2.6 ^a	233.6±12.6 ^{ab}	85.2±3.5 ^{ab}	251.2±13.5 ^{ab}	4.75±0.67	<u>19.75±3.84</u>
	T ₁₀ D ₇ I ₈₀	92.3±2.6 ^c	238.2±11.6 ^{abc}	108.8±1.4 ^{def}	297.6±17.7 ^{bc}	6.61±1.38	24.87±4.10
	T ₁₀ D ₁₀ I ₇₀	79.6±2.2 ^{ab}	269.6±14.0 ^{cd}	92.8±4.2 ^{bc}	278.1±16.9 ^{bc}	<u>3.90±0.18</u>	25.95±2.76
	T ₁₀ D ₁₄ I ₉₀	91.6±6.8 ^{bc}	250.8±12.2 ^{abc}	110.1±3.7 ^{ef}	274.4±27.4 ^{ab}	5.52±1.06	24.35±2.77
AL		93.6±3.6^c	254.4±13.7 ^{bc}	112.4±2.2 ^{ef}	293.6±13.2 ^{bc}	5.73±0.91	20.08±5.70

Table 5 Leg muscle and breast muscle color on day 42 ($\bar{X} \pm SE$)

group		leg muscle			breast muscle		
		<i>L*</i>	<i>a*</i>	<i>b*</i>	<i>L*</i>	<i>a*</i>	<i>b*</i>
FR	T ₅ D ₇ I ₉₀	41.7±1.7	19.5±1.2	13.7±0.6	51.2±0.9	10.6±0.8	<u>16.0±0.9</u>
	T ₅ D ₁₀ I ₈₀	<u>39.8±1.9</u>	17.7±0.7	13.8±0.7	52.0±1.7	11.3±0.9	18.2±0.8
	T ₅ D ₁₄ I ₇₀	40.6±1.5	<u>16.3±1.8</u>	13.6±0.5	53.7±0.9	11.5±2.8	18.4±0.2
	T ₇ D ₇ I ₇₀	42.2±1.6	17.3±0.6	14.6±0.9	<u>49.7±1.5</u>	12.1±0.7	<u>15.3±1.1</u>
	T ₇ D ₁₀ I ₉₀	42.4±0.5	18.6±0.6	13.5±1.2	50.6±0.8	11.1±0.5	16.3±0.2
	T ₇ D ₁₄ I ₈₀	41.4±0.7	18.0±0.4	<u>12.9±0.4</u>	51.9±1.3	<u>9.3±1.2</u>	16.2±0.0
	<u>T₁₀D₇I₈₀</u>	42.2±1.6	17.1±0.3	14.0±0.5	52.4±5.0	11.5±0.5	17.6±3.4
	T ₁₀ D ₁₀ I ₇₀	—	—	—	50.4±1.2	11.9±0.9	17.2±1.0
	T ₁₀ D ₁₄ I ₉₀	41.4±3.6	20.9±0.9	14.3±1.7	50.8±4.5	13.1±0.5	16.5±1.7
AL		45.8±1.1	18.3±1.0	16.2±0.8	51.0±0.9	12.6±0.7	17.2±0.5

and FR except T₅D₇I₉₀ and T₁₀D₁₄I₉₀ all had lower *a** values of leg muscle than AL. *a** values of breast muscle in FR except T₁₀D₁₄I₉₀ were all lower than in AL. T₅D₁₄I₇₀ had the highest *L** and *b** values of breast muscle, while T₅D₇I₉₀ had the lowest. Simultaneously, we found leg muscle had lower *L** and *b** values and higher *a** value than breast muscle.

Feed conversion

Feed consumption and conversion are shown in Table 6. Daily feed intake (DFI) of FR during 1–23 days was all lower than that of AL, which showed that the feed intake of chickens was indeed restricted. The average daily gain (ADG) of FR during 1–23 days except T₅D₇I₉₀ was all lower than that of AL, with T₅D₁₄I₇₀ being the lowest. DFI of FR except group T₅D₁₄I₇₀ and T₇D₇I₇₀ were all higher, and ADG of FR groups except group T₁₀D₁₀I₇₀ was all some lower, than the AL group during 24–35 days. DFI of FR groups was all lower, and ADG of FR groups (except group T₅D₁₀I₈₀) were all higher than the AL group; and group T₅D₇I₉₀ had the highest ADG during 36–42 days. It showed that the compensatory growth was mostly exhibited at later days of broilers. Feed conversion ratio (FCR) of FR was all lower than that of AL. Perhaps it was a random error too big that we did not find the statistical difference between groups about DFI and ADG.

Hormone level

T₃, T₄ and GH levels of T₅D₇I₉₀, T₅D₁₄I₇₀ and AL are shown in Table 7. Differences of T₃, T₄ and GH levels, as well as ratio of T₄/T₃ among the three groups, were not significant. However, T₃ and GH of the two FR groups were both lower, with T₄/T₃ higher, than those of AL at 24th and 42nd days. T₄ of the two FR groups were higher than that of AL at the 24th day. T₃, T₄ and T₄/T₃ all decreased, but GH increased at the 42nd day compared with that at the 24th day.

Discussion

The timing, duration and intensity of early feed restriction (FR) were studied with orthogonal experiment, a partial experiment. We found early FR to 90% from day 5 to day 11 had the highest BW, carcass weight, whole eviscerated weight, leg and breast muscle, while that early FR to 70% from day 5 to day 18 had the lowest, which was in line with previous findings. Camacho et al. (2004) reported that quantitative FR at the 7th day had the optimized effects. Govaerts et al. (2000) reported FR of chicks to 80% or 90% from day 4 to day 7 or day 4 to day 11 had no effects on BW of age of 42 days; however, the average BW of FR groups was higher than that of AL broilers. Tůmová et al. (2002) found broilers feed-restricted from day 7 to day 11 by

Table 6 DFI, ADG and FCR during the feeding period

group		DFI _{1–23} /(g·d ⁻¹)	ADG _{1–23} /(g·d ⁻¹)	DFI _{24–35} /(g·d ⁻¹)	ADG _{24–35} /(g·d ⁻¹)	DFI _{36–42} /(g·d ⁻¹)	ADG _{36–42} /(g·d ⁻¹)	FCR
FR	T ₅ D ₇ I ₉₀	51.7	30.2	102.6	58.5	79.8	60.0	1.85
	T ₅ D ₁₀ I ₈₀	51.2	27.9	93.0	59.3	73.9	36.7	1.86
	T ₅ D ₁₄ I ₇₀	46.0	<u>24.4</u>	<u>91.1</u>	<u>51.6</u>	81.7	<u>32.6</u>	1.86
	T ₇ D ₇ I ₇₀	50.3	27.2	<u>86.0</u>	59.4	73.8	41.8	1.81
	T ₇ D ₁₀ I ₉₀	51.3	29.4	94.6	56.2	76.9	46.8	<u>1.80</u>
	T ₇ D ₁₄ I ₈₀	45.3	25.6	94.5	57.4	<u>72.6</u>	51.6	1.82
	T ₁₀ D ₇ I ₈₀	51.5	29.6	94.8	55.8	80.5	46.5	1.82
	T ₁₀ D ₁₀ I ₇₀	<u>40.3</u>	26.5	96.8	62.2	81.4	43.1	1.83
	T ₁₀ D ₁₄ I ₉₀	46.3	27.7	95.8	55.3	80.1	49.9	1.81
AL		53.4	29.7	91.8	60.6	82.3	44.4	1.87

Note: DFI_{1–23} means daily feed intake during 1–23 days, DFI_{24–35} means daily feed intake during 24–35 days, DFI_{36–42} means daily feed intake during 36–42 days, ADG_{1–23} means the average daily gain during 1–23 days, ADG_{24–35} means the average daily gain during 24–35 days, ADG_{36–42} means the average daily gain during 36–42 days.

Table 7 Levels of T₄, T₃ and GH and T₄/T₃ on day 24 and d 42 ($\bar{X} \pm SE(\text{ng} \cdot \text{mL}^{-1})$)

group	T ₃		T ₄		T ₄ /T ₃		GH	
	24th day	42nd day	24th day	42nd day	24th day	42nd day	24th day	42nd day
T ₅ D ₇ I ₉₀	0.60±0.04	0.47±0.05	47.5±2.6	25.0±1.6	80.1±6.5	53.9±6.1	0.15±0.03	0.18±0.05
T ₅ D ₁₄ I ₇₀	0.55±0.04	0.51±0.05	48.3±3.8	29.6±2.6	88.5±17.8	57.0±8.0	0.10±0.05	0.24±0.07
AL	0.63±0.03	0.55±0.07	44.5±2.7	25.6±2.8	71.6±14.9	46.9±6.6	0.27±0.08	0.31±0.05

6 g·d⁻¹ per chick or from day 7 to day 14 by 8 g·d⁻¹ per chick had higher BW at 56 days. Yang et al. (2009) reported Ross chicks received protein or energy reduced feed during 8–14 days had higher BW at 42 days and higher feed conversion ratio during the feeding period. The present results explained those previous conflicted results that early FR for short time and low intensity induced a compensatory growth at later feeding period, but early FR for long time and high intensity stunted the growth and development of birds, and the dwarfing effect became progressively worse as the duration of severe FR increased. Young animals severely feed-restricted or affected by severe diseases often failed to express compensatory growth (Hornick et al., 2000). Yu et al. (1992) suggested that animals with stunted bone growth did not recover as well as animals which suffered from wasting of soft tissues. Dressing percentage of FR broilers decreased without statistical significance in the paper of Mahmood et al. (2007), which was in agreement with the present result that FR broilers had lower RC and RW, which, however, did not reach the significant level. The more severe the FR, the lower the RC and RW are, just as T₅D₁₄I₇₀. FR increased the byproducts of broilers.

Zhan et al. (2007) reported that FR increased fat deposition. Onbaşlar et al. (2009) did not find that early FR had any effects on fat deposition. Mark et al. (2003) reported that FR of broiler breeds decreased the abdominal fat deposition and T₃ level in plasma. Birds have the ability to store large quantities of excess energy in liver and abdominal fat tissue. Variations in nutrient intake and status were communicated to the liver and other internal organs by alterations in levels of T₃ in the plasma, which responded acutely to dietary changes and then changed its fat metabolism (Mark et al., 2003). During fasting, circulating T₃ was depressed while T₄ increased (Marek et al., 2006; Sun et al., 2006; Andrea et al., 2009), which was in line with the present result that there was a lower concentration of T₃ in FR broilers and a higher concentration T₄ in FR broilers at the 24th day, suggesting a lower metabolic rate during feed restriction. The energy and nutrients to support compensatory growth may come from the reduction of maintenance requirements during refeeding after a period of FR. In our study, all the nine FR programs increased fat deposition at the 42nd day, and T₅D₇I₉₀ increased the lean meat ratio of breast and leg muscle by 1.8%, while T₅D₁₄I₇₀ decreased the lean meat ratio of breast and leg muscle weight by 1.5%.

T₄ was deiodinated to T₃ that was the main metabolic stimulating hormone in the periphery (Andrea et al., 2009). T₄/T₃ ratio was higher in FR broilers than that of AL broilers at the 24th day. It indicated that animals could cope with FR challenge by decreasing the transformation of T₄ to T₃ or increasing catabolism of T₃, and by decreasing the basal metabolism and thus allowing the organism to spare energy to deposit protein and fat. At the same time, FR broilers could keep the metabolism till the market age. T₅D₇I₉₀ had higher fat and meat deposition ratio compared with AL, while

T₅D₁₄I₇₀ had higher fat deposition ratio and lower meat deposition ratio, despite its higher T₄/T₃ than that of AL, which shows that T₄ and T₃ may mainly modulate the fat metabolism and have no relation with the meat deposition of broilers.

The normal growth rate of broiler depends in part on concentration of circulating T₃ being maintained at a well-controlled physiological “set-point”, which is achieved through an inhibitory feedback loop between T₃ and GH. These may explain the present result that GH at the 42nd day was higher than that at the 24th day because T₃ of broilers at the 42nd day was all lower than that at the 24th day. One of the responses to GH administration is the suppression of voluntary feed intake, attributed to improvement in the efficiency of nutrient utilization and reduced need for ingested substrates (Wang et al., 2000). GH is a major anabolic agent with effects on protein, fat and carbohydrate metabolism and has the ability of anti-lipogenic effect in chickens (Scanes, 2009). These just explained the present result that GH increased at the 42nd day compared with that at the 24th day, which resulted in a decrease in DFI during 36–42 days compared with that during 24–35 days. These also turned out that GH of both T₅D₇I₉₀ and T₅D₁₄I₇₀ was lower than that of AL at the 42nd day, and resulted that DFI of FR broilers during 36–42 days was all higher than that of AL, and RA of FR broilers at the 42nd day was higher than that of AL broilers.

Bruggeman et al. (1997) determined FR produced higher plasma concentration of GH, while in our study, GH of FR broilers decreased at the 24th and 42nd days compared with AL broilers. The unconformity may be due to the measurement of GH of broilers after FR, while Bruggeman et al. (1997) measured GH of broilers during FR, or perhaps it was the variations of FR. In the report of Govaerts et al. (2000), restricted broilers with the compensatory growth had lower GH; however, the broilers without the compensatory growth had higher GH. High circulating levels of GH allowed enhanced fat mobilization. In the present study, FR program T₅D₁₄I₇₀ did not have compensatory growth, while the program T₅D₇I₉₀ had compensatory growth. Both the two programs had lower GH and higher RA, which may show that GH has no relation with the growth rate but with the fat metabolism.

FR broilers had a higher growth capability of leg muscle and lower growth capability of breast muscle. Vasilatos et al. (2000) reported that GH injection decreased the deposition of breast muscle and the leg muscle of broilers, which may be differences of sensitivity of muscle fiber types. Color is one of the main characteristics of meat quality, which is determined by myoglobin content that depends on the myofibril types in muscle. There are four myofibril types in muscle. Breast muscle consists mainly of Type IIB with lower myoglobin, and leg muscle consists mainly of Type I and Type IIA with higher myoglobin, which caused that the leg muscle had higher *a** and lower *L** values than the breast muscle. Yue et

al. (2007) reported that FR broilers had higher myofibril of Type I and Type IIA in lateral gastrocnemius muscle at the 14th day, but lower I type myofibril at the 63rd day. Myofibril type transform followed the sequence of I to IIA to IIB with age. In the present experiment, we found that FR decreased the lightness (L^*) and yellowness (b^*) values of the leg muscle, indicating that the leg muscle in FR broilers had more myofibril of Type I and Type IIA, and FR delayed the myofibril type conversion and improved the leg muscle quality. It has not been completely elucidated the pathway mediating the effect of nutritional deficiency on myofibril type transformation, yet the reduced serum concentration of thyroid hormones was suggested to be involved in the mechanism. Hypothyroidism leads to preferential expression of slower fiber types, while hyperthyroidism enhances the content of fast fibers in rats (Vadaszova et al., 2004). We detected that T_3 and T_4 both decreased in FR at the 24th and 42nd day.

Conclusion

In summary, early (5 days) feed restriction for low intensity (90%) and short duration (for 7 days) caused that FR broilers not only had compensatory growth at the 24th day with higher meat production performance at the 42nd day, but also exceeded the growth of AL broilers. And early (5 days) feed restriction for high intensity (70%) and long duration (for 14 days) caused that broilers were stunned, with breast muscle instead of leg muscle restricted in growth. While the other FR programs also showed the ability of compensatory growth partially inhibited. The feed restriction could improve the leg muscle color and increase the production of broiler byproducts. Lower T_3 and GH concentration and higher T_4/T_3 ratio in plasma had feed conversion rate and fat deposition increase in FR broilers, which has no relation with the meat production and growth rate.

Acknowledgements

This research was supported by the Fund of Scientific and Technological Development Projects of Hebei Province (No. 07220401D-9).

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